Publication 5002

AGRICULTURAL MATERIALS HANDLING MANUAL

PART 3 PROCESSING EQUIPMENT

SECTION 3.5

MANURE

Agriculture Canada

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SECTION 3.5

MANURE

The Agricultural Materials Handling Manual is produced in several parts as a guide to designers of materials handling systems for farms and associated industries. Sections deal with selection and design of specific types of equipment for materials handling and processing. Items may be required to function independently or as components of a system. The design of a complete system may require information from several sections of the manual.

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SECTION 3.5 MANURE

3.5.1 GENERAL

Most animal production units involve some form of confinement housing. The housing may be either warm or cold. Exercise areas may be covered or uncovered, paved or unpaved. Because of potential odor, confinement units should be downwind of nearby homes and businesses and, because of potential liquid runoff, they should not be adjacent to streams.

For dairy cattle additional care is necessary to meet clean milk requirements, and to cope with the large quantities of manure.

Swine production varies greatly from small groups of hogs raised mainly on pasture to automated housing for several thousand animals. Swine production includes farrowing, dry sow, nursery and finishing; manure management therefore involves a systems approach to integrate all sources of swine manure for recycling.

Fresh poultry manure has higher nutrient and solids content, hence useful byproducts are more likely to be economic. Some of these methods include drying, refeeding, and composting.

Most traditional agricultural systems likely will involve recycling manure back onto cropland where air and water pollution standards can be met. Understanding the characteristics of manure permits proper selection and design of a system to be used.

3.5.2 PROPERTIES

The physical and chemical properties of animal manures depend on animal species, age, health and nutrition. An appreciation of these properties is useful for designing the components that make up a manure handling system, for timing of land spreading and when deciding the quantities that can safely be applied. Reference (6) should be used as a guide to land spreading of manures to avoid environmental pollution under Canadian climatic conditions.

The properties of manure ultimately handled may be very different from the as-voided properties where urine and feces are mixed to form a slurry. Bedding may be mixed with the manure or evaporation may be sufficient to form a stackable solid. Rain, wash water and leakage from waterers may produce a free-flowing liquid. Biochemical activities alter the chemical properties due to microbial activity, leading to nitrogen losses (volatilization of ammonia or gaseous nitrogen). Table 3.5.1 summarizes the quantities of manure produced daily by domestic animals and the average chemical composition as voided.

The size of particles contained in the solids fraction will depend on the ration fed the animal. Coarse dense solids tend to settle, forming a layer at the bottom of storage tanks. Swine and high-roughage cattle manure will exhibit these characteristics. Slurries with a high proportion of fine particles will stratify into settled solids, liquid and a floating scum; agitation equipment is required to remove them from storage. Manure slurry acts as a non-Newtonian fluid, hence the pumping characteristics cannot be determined from properties of water. See Figure 3.5.45 and 3.5.46 for flow characteristics in pipelines.

3.5.3 COLLECTION AND TRANSFER SYSTEMS

Handling and management of manure on modern farms is complicated by a continuing increase in animal numbers on individual farms, shortages or high costs of suitable bedding, pollution control and compliance regulations, rising costs of inorganic fertilizers, and improvements to reduce drudgery in livestock work. These economic, legal and social considerations make it desirable to control the manure from production to final utilization.

Fresh manure undergoes physical and chemical changes with time, due to moisture change, mixing with bedding or forage and either aerobic or anaerobic breakdown.

TABLE 3.5.1 Animal Waste Characteristics[1]

Animal	Size (kg)	Wet Manure[2] (kg/day)	Wet Manure (m^3/day)	Total Solids (kg/day)	Nitrogen (kg/day)	P_2O_5 (kg/day)	K_2O (kg/day)
Dairy	635	45	0.045	6.8	0.25	0.07	0.2
Beef	430	27	0.028	4.0	0.2	0.05	0.14
Poultry	2.3	0.14	0.0001	0.04	0.001	0.001	0.0005
Swine	45	5.1	0.0051	0.64	0.02	0.05	0.02
Sheep	45	3.2	0.003	0.7	0.04	0.02	0.04
Animal	**Size (lb)**	**Wet Manure** (lb/day)**	**Wet Manure (ft^3/day)**	**Total Solids (lb/day)**	**Nitrogen (lb/day)**	**P_2O_5 (lb/day)**	**K_2O (lb/day)**
Dairy	1400	100	1.6	15	0.55	0.16	0.4
Beef	950	60	1.0	9	0.4	0.1	0.3
Poultry	5	0.31	0.005	0.08	0.003	0.003	0.001
Swine	100	11.2	0.18	1.4	0.048	0.027	0.035
Sheep	100	7.1	0.11	1.6	0.09	0.034	0.085

[1]All values are averages taken from published literature
[2]Assuming no dilution
From: *Canada Animal Manure Management Guide* (1979). Publication 1534, Agriculture Canada, Ottawa

Housing design will influence significantly this primary change. Manure handling equipment and systems, therefore, should be an essential part of the planning of an animal operation. Plans offered by the Canada Plan Service show manure handling alternatives (see Figures 3.5.1 to 3.5.5). Sanitation and safety features of manure storages and associated facilities should also conform to the Canadian Farm Building Code as well as local provincial pollution control regulations.

The choice of a manure handling system is based on such factors as type of animal, management system, building

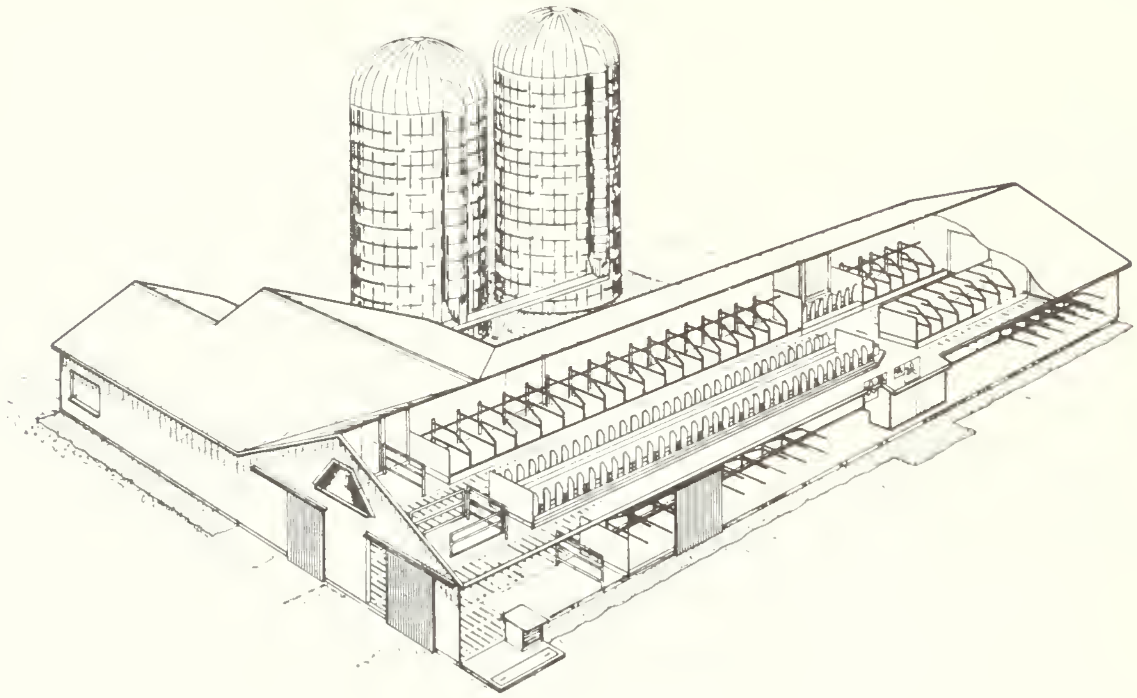
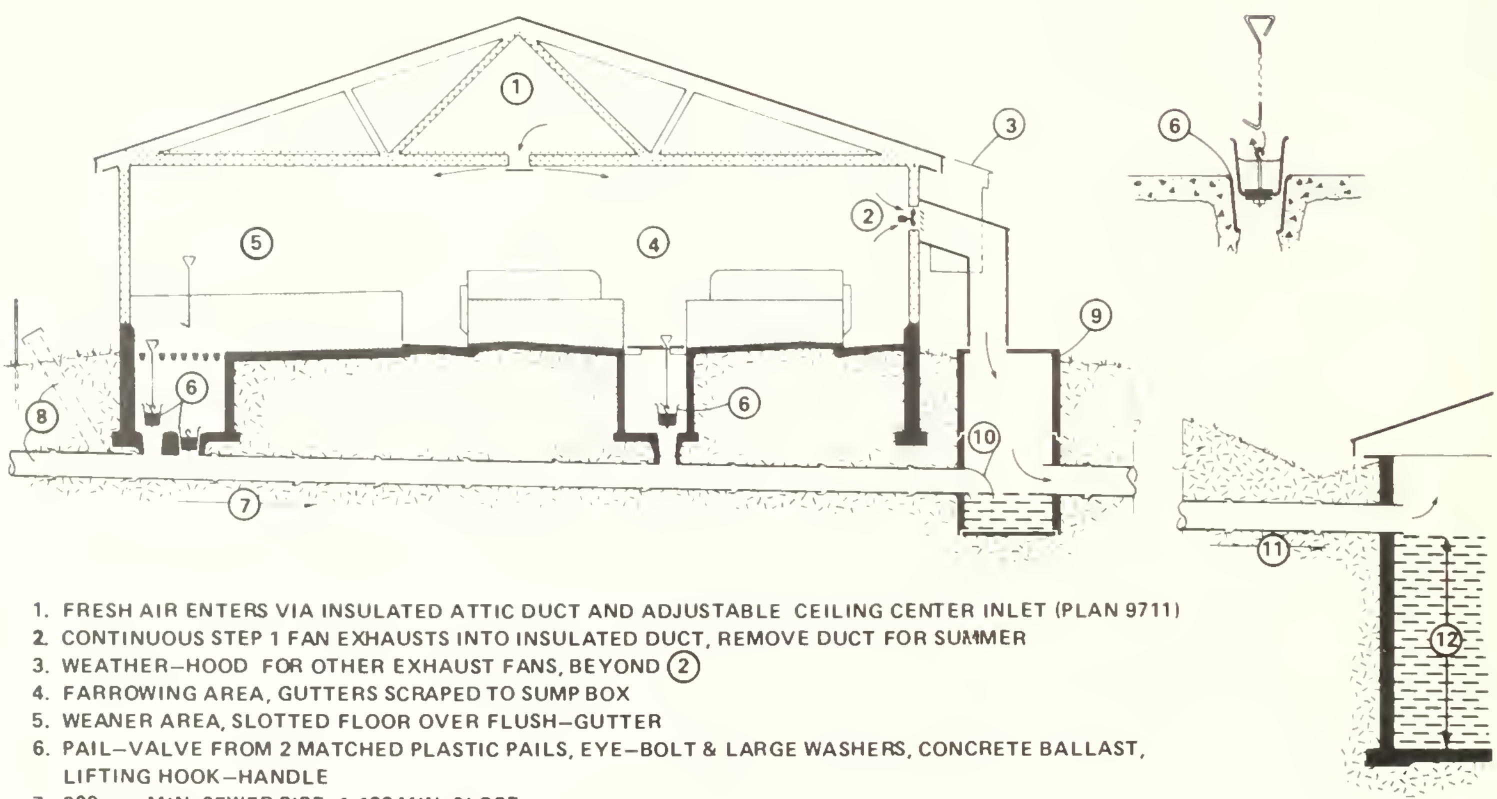
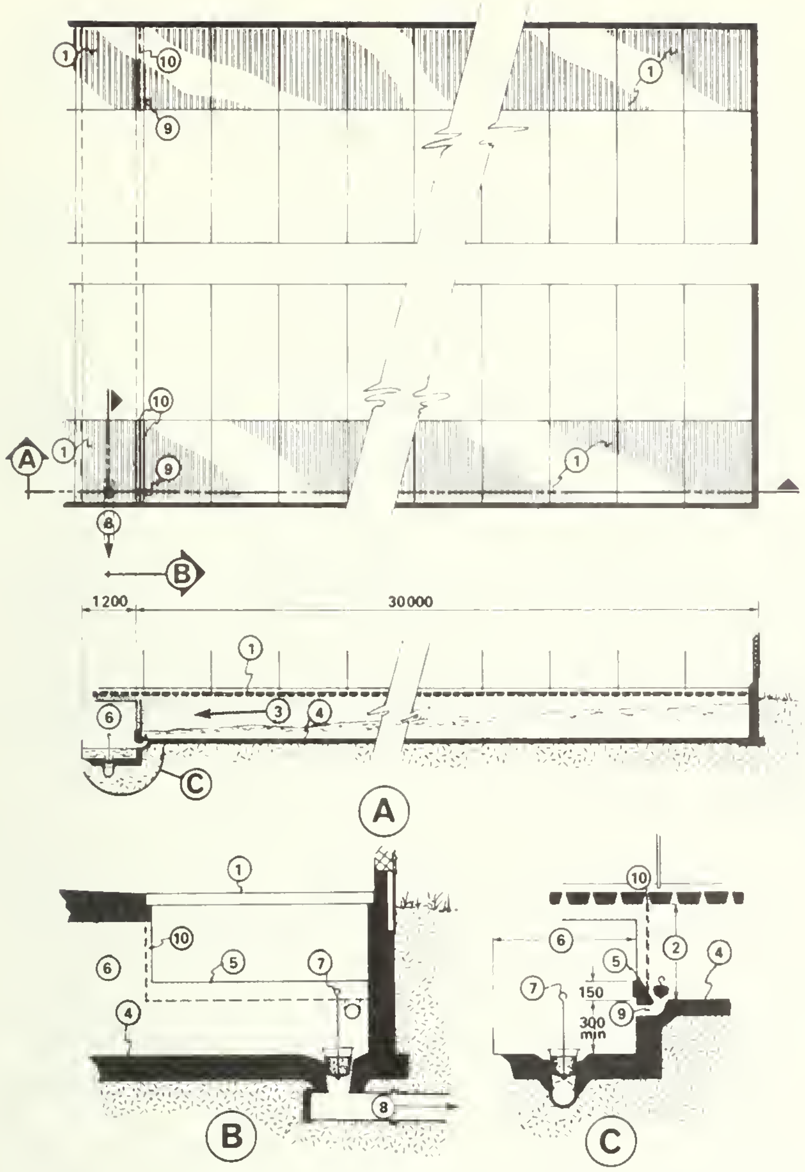


Figure 3.5.1 Free stall dairy system - 60 cows - slotted floor (CPS Plan 2102)



1. FRESH AIR ENTERS VIA INSULATED ATTIC DUCT AND ADJUSTABLE CEILING CENTER INLET (PLAN 9711)
2. CONTINUOUS STEP 1 FAN EXHAUSTS INTO INSULATED DUCT, REMOVE DUCT FOR SUMMER
3. WEATHER–HOOD FOR OTHER EXHAUST FANS, BEYOND (2)
4. FARROWING AREA, GUTTERS SCRAPED TO SUMP BOX
5. WEANER AREA, SLOTTED FLOOR OVER FLUSH–GUTTER
6. PAIL–VALVE FROM 2 MATCHED PLASTIC PAILS, EYE–BOLT & LARGE WASHERS, CONCRETE BALLAST, LIFTING HOOK–HANDLE
7. 200mm MIN. SEWER PIPE, 1:100 MIN. SLOPE
8. FROM SWINE GROWER/FINISHER UNIT, ETC. (OR 100mm CLEANOUT PIPE WITH CAP)
9. COLLECTOR PIT MADE FROM 1200mm CONCRETE PIPE
10. GAS TRAP, FROM 200mm PIPE ELBOW
11. 300mm MIN. SEWER PIPE TO (12)
12. LONG–TERM MANURE STORAGE, MAX. LIQUID LEVEL AT OUTLET INVERT OF (11)

Figure 3.5.2 Typical liquid swine manure system with gravity flow to remote long-term storage



1 slotted floor over manure channel
2 depth depends on channel length
3 liquid manure surface, slopes 1:00 to 1:30
4 channel bottom water tight, smooth and level
5 overflow dam, top edge level
6 cross—channel accumulates manure 2–3 days
7 pail-valve
8 200 mm sewer pipe to long term storage, min slope 1:100
9 channel drain from 100 mm plastic pipe elbow, rubber plug & eye-hook
10 25mm grooves in sides of channel, 19mm plywood sluice gate optional

Figure 3.5.3 Continuous flow manure system, adapted to a slotted-floor swine growing/finishing barn (CPS Plan M-3428)

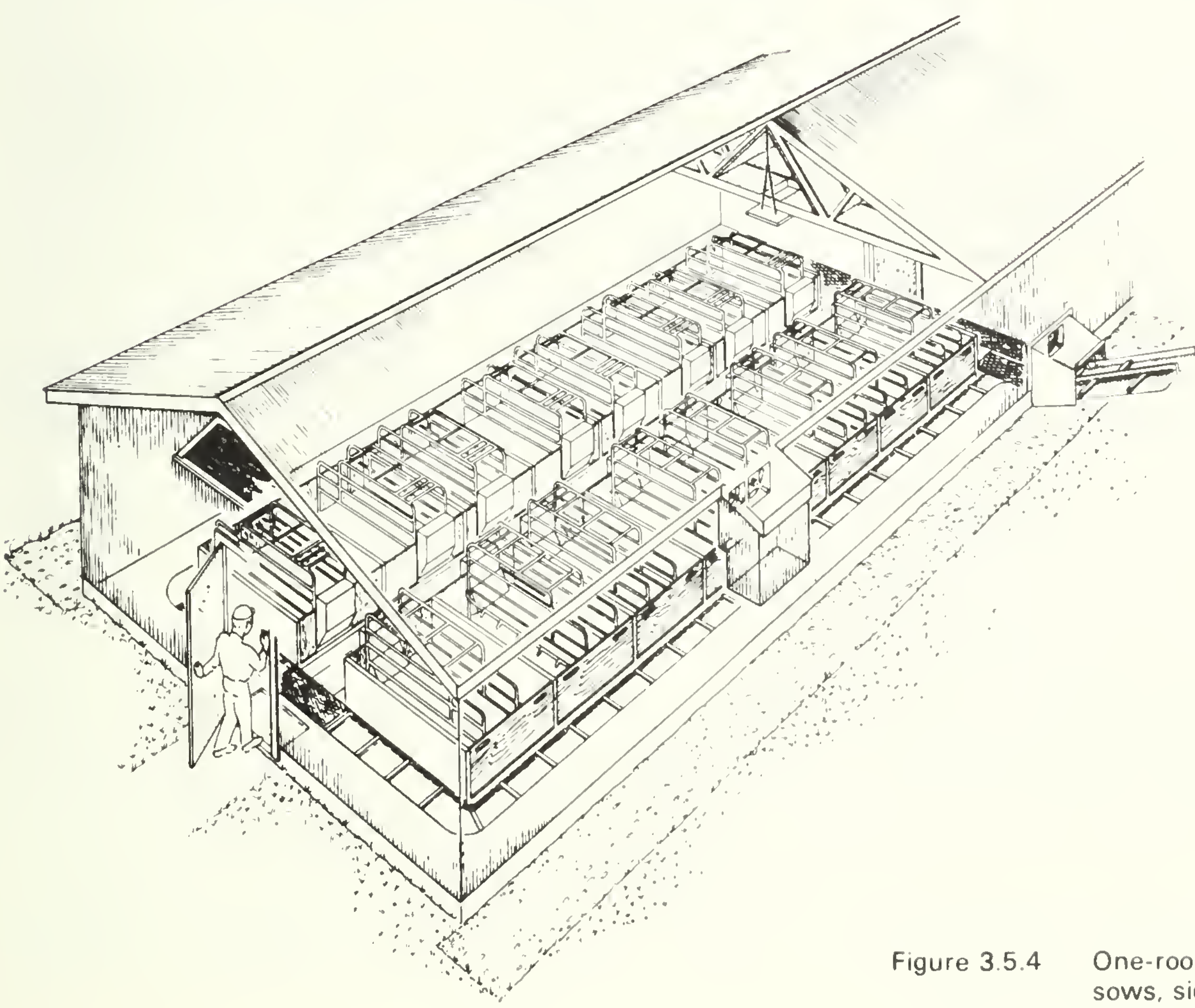


Figure 3.5.4 One-room continuous farrowing system - 50 sows, side creeps (CPS Plan 3301)

design, climate, soil type, cropping practices, land availability for spreading, availability of water, and amount of investment available for mechanical equipment.

Figures 3.5.6 to 3.5.9 illustrate available management alternatives, types of manure, and collection and transfer equipment for different animal enterprises. These figures are useful for comparing building and equipment needs and matching these needs to individual farms. Ogilvie et al (21) have extended this approach by developing Shortest Path Network Analysis (SPNA) methods for dairy cattle and swine. This permits a determination of cost in time, money and energy for each portion of a pathway. The minimum cost system in terms of money will be best if time constraints also are met. Figures 3.5.10 and 3.5.11 show the alternatives used by Ogilvie et al (21) in their SPNA.

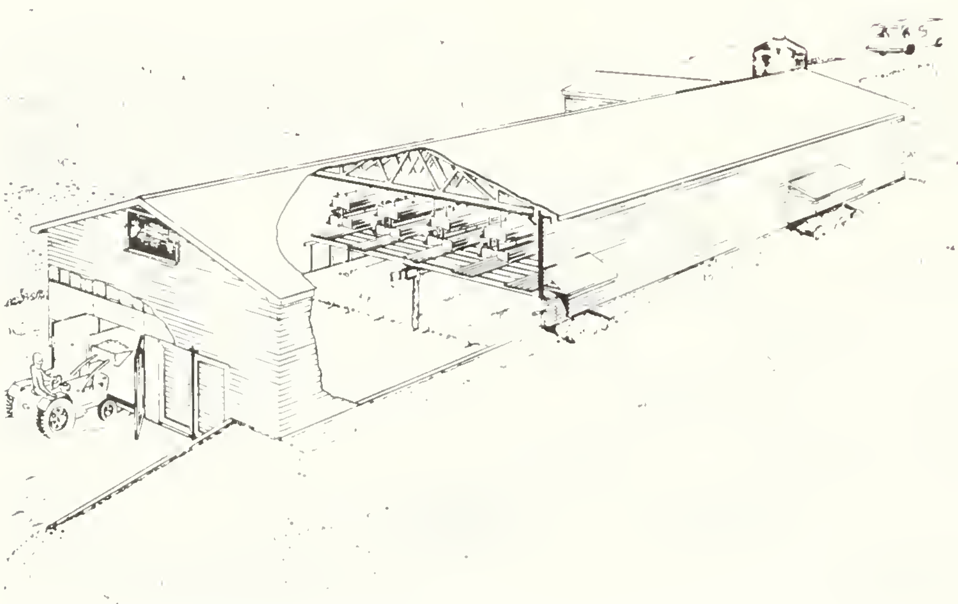


Figure 3.5.5 Deep pit caged laying house (CPS Plan 5211)

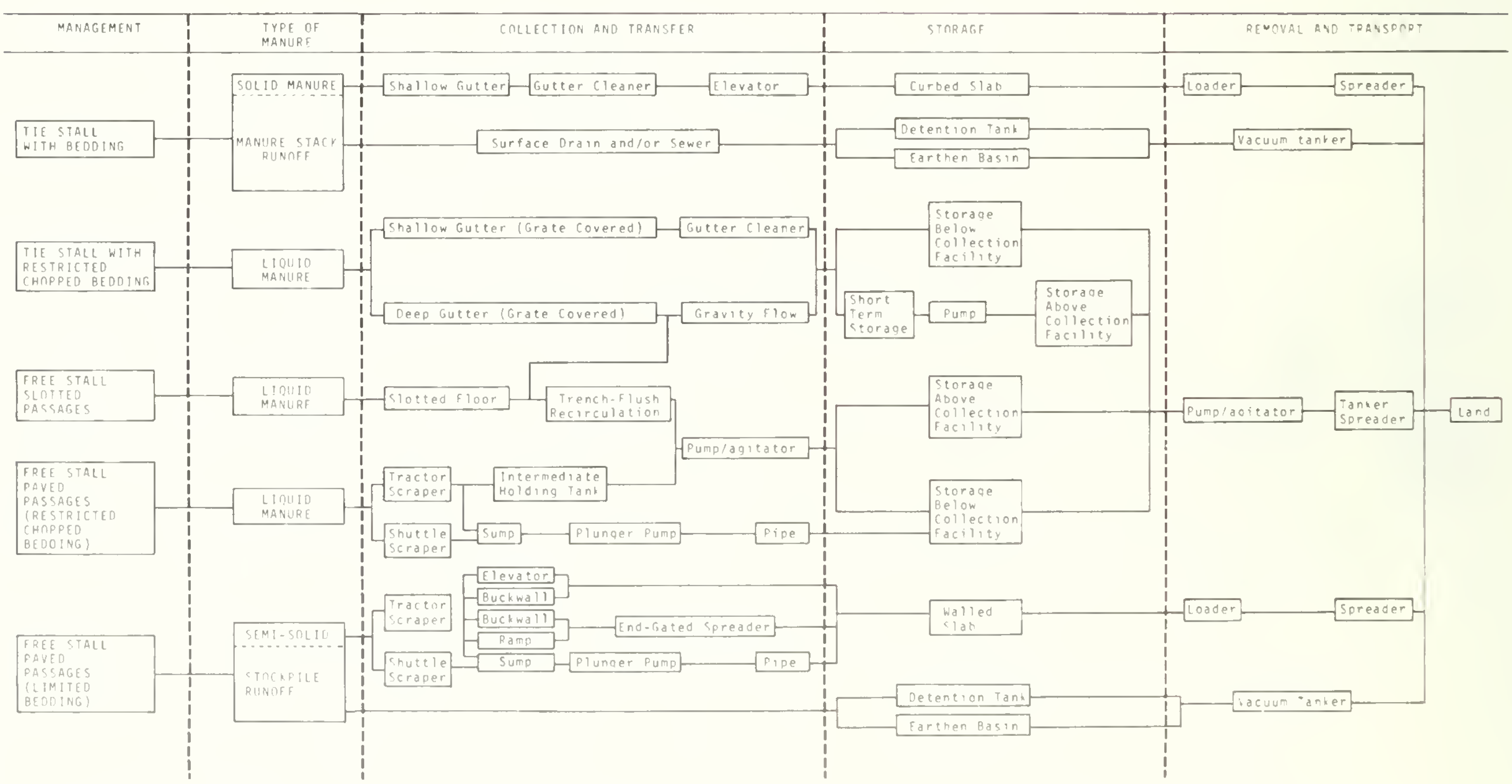


Figure 3.5.6 Manure handling systems for dairy cattle

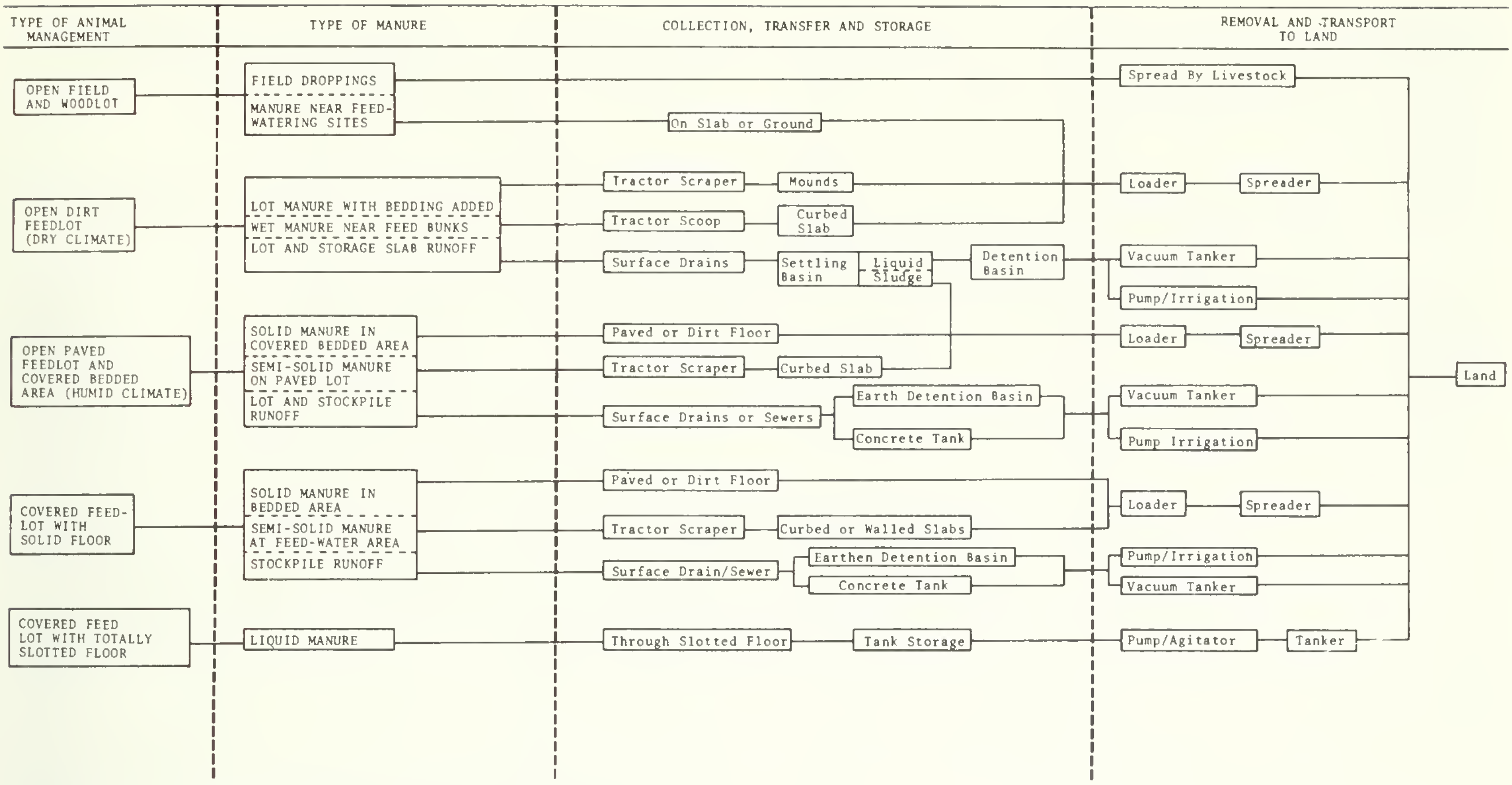


Figure 3.5.7 Manure handling systems for beef cattle

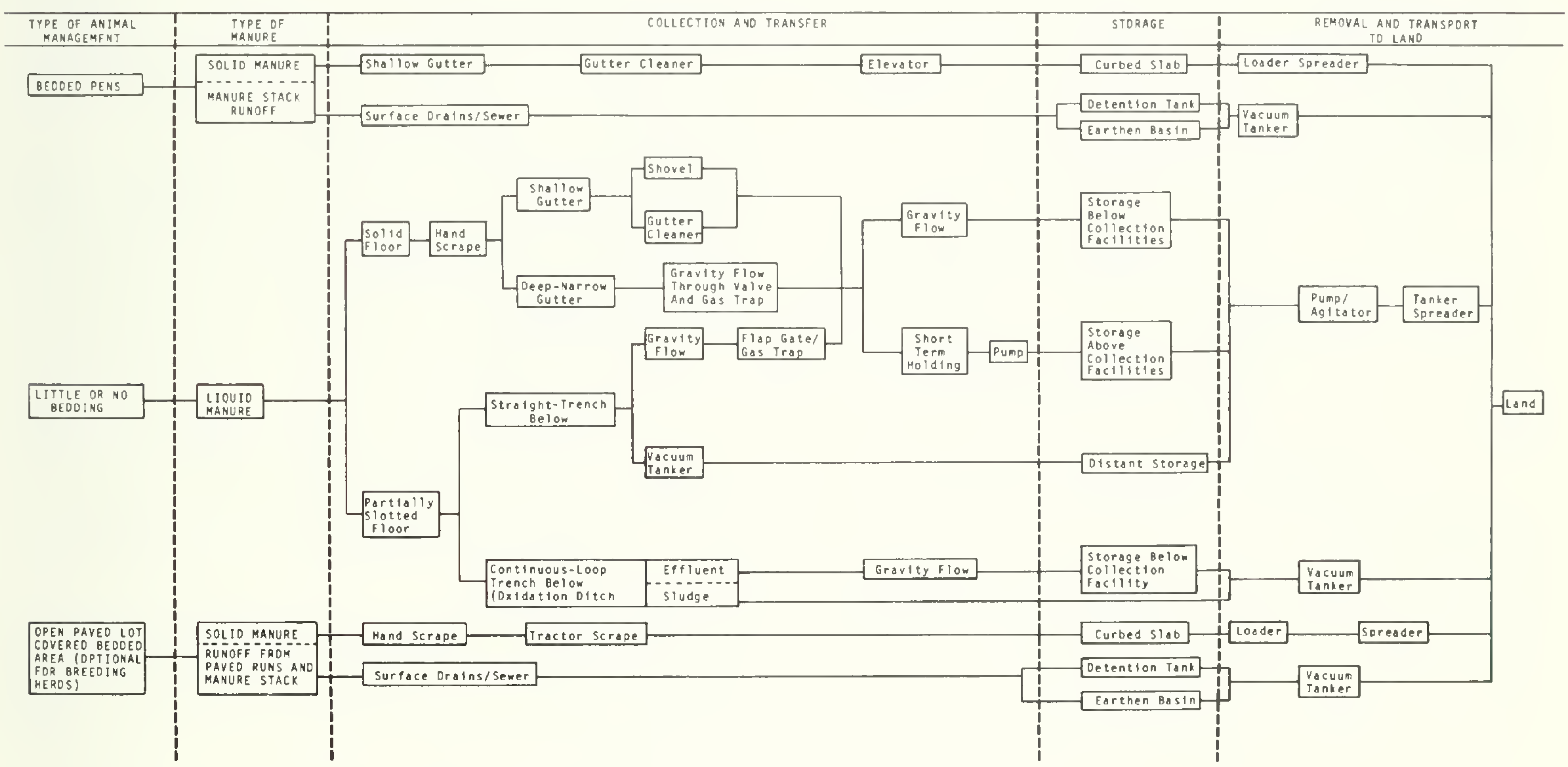


Figure 3.5.8 Manure handling systems for Swine

3.5.3.1 Water Flushing

In warm controlled-environment barns where freezing is not a problem, relatively simple hydraulic methods can be used to transfer liquid manures from livestock pens to treatment and/or long-term storage facilities.

One method occasionally used is a shallow manure gutter sloped at about 1:200 towards the outlet. To flush, liquid supernatant from the storage or treatment process is periodically recirculated to the upstream end of each gutter; flushing with fresh water would be more sanitary but would multiply the volume of liquid manure to be handled later. The second best alternative is to use waste treated aerobically to reduce odors. An effective flushing wave is generated by using a high-capacity recirculating pump or by using a smaller recirculation system to accumulate flushwater in a dump-tank at the upstream end of each gutter. About 700 L tank capacity effectively flushes swine finishing manure from a shallow gutter 1.2 m wide. The tank may be dumped by manual valve, automatic tip, or flushing siphon.

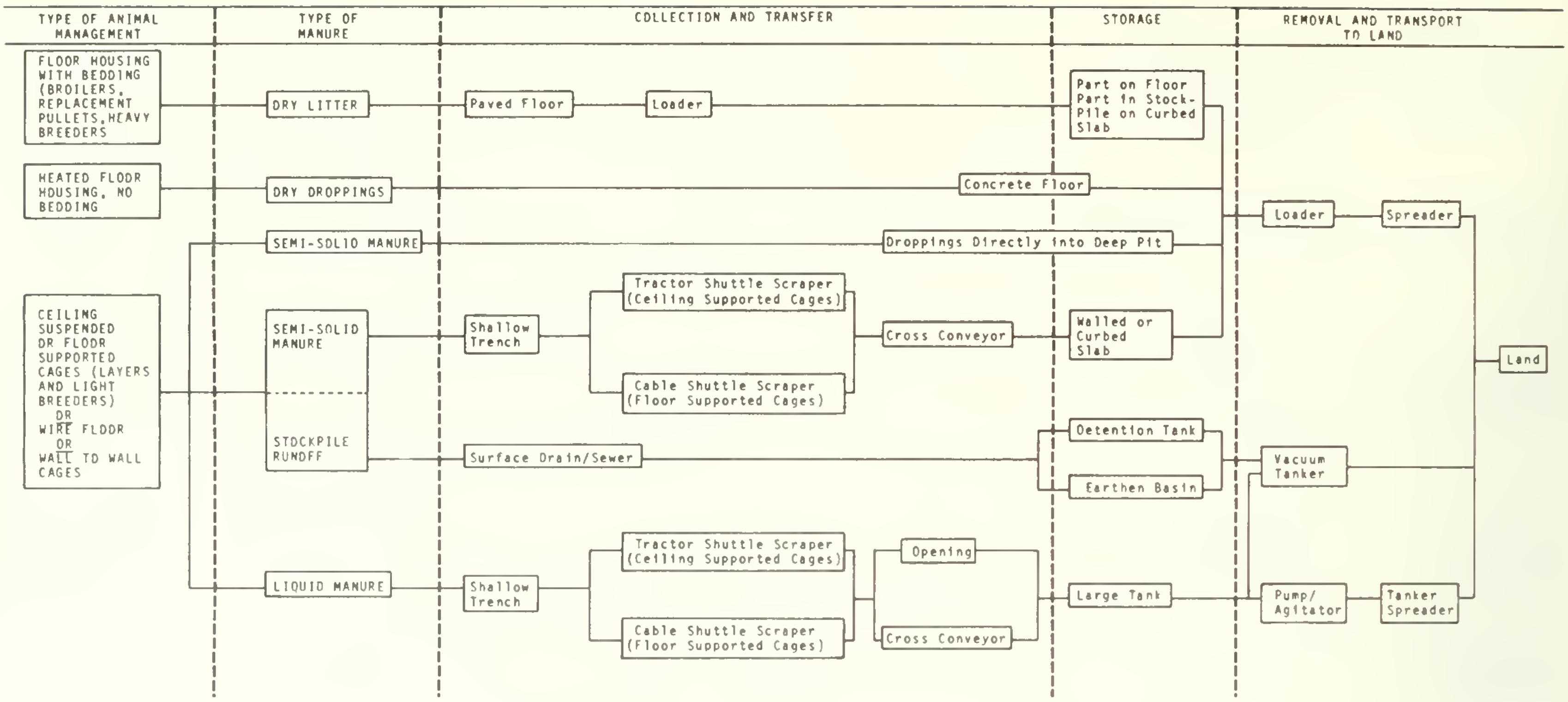


Figure 3.5.9 Manure handling systems for poultry

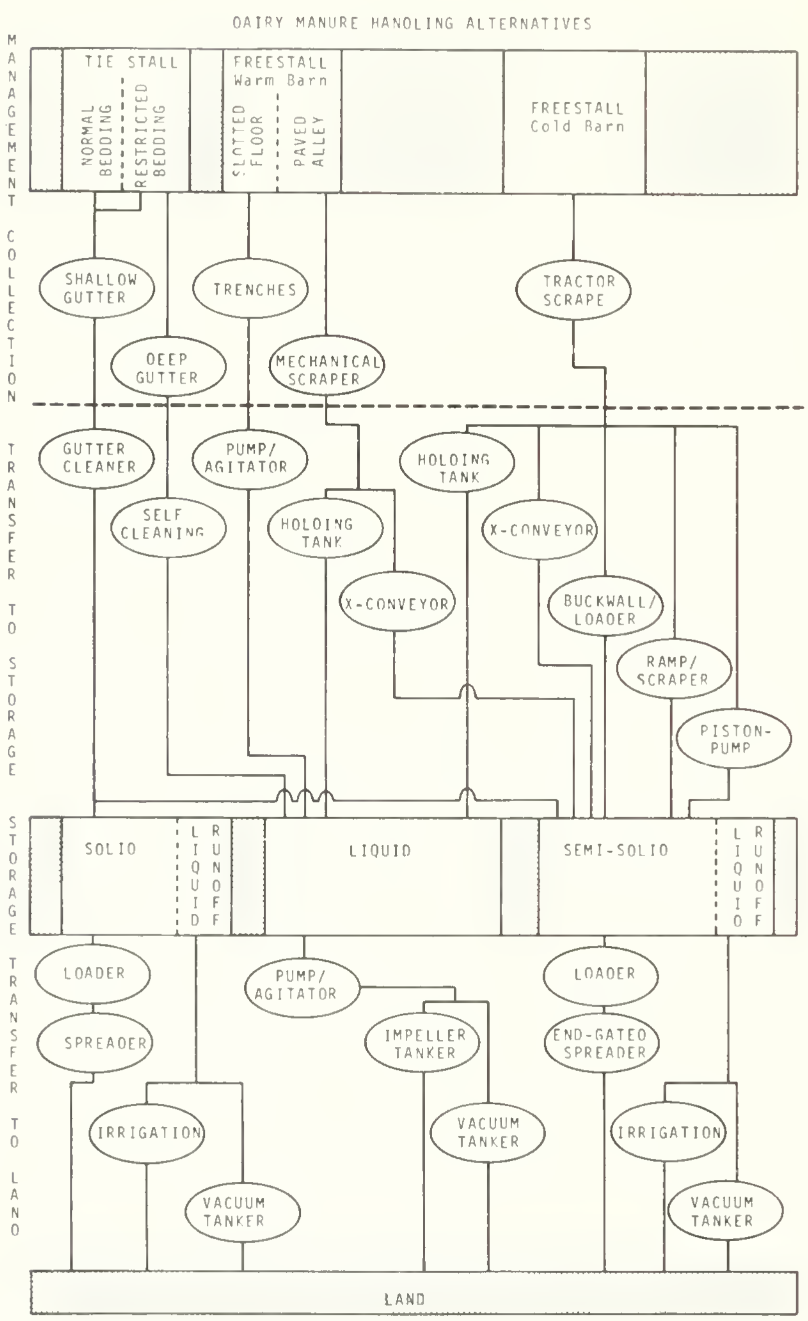


Figure 3.5.10 Simplified network for SPNA of dairy manure handling alternatives (from J.R. Ogilvie et al. (21))

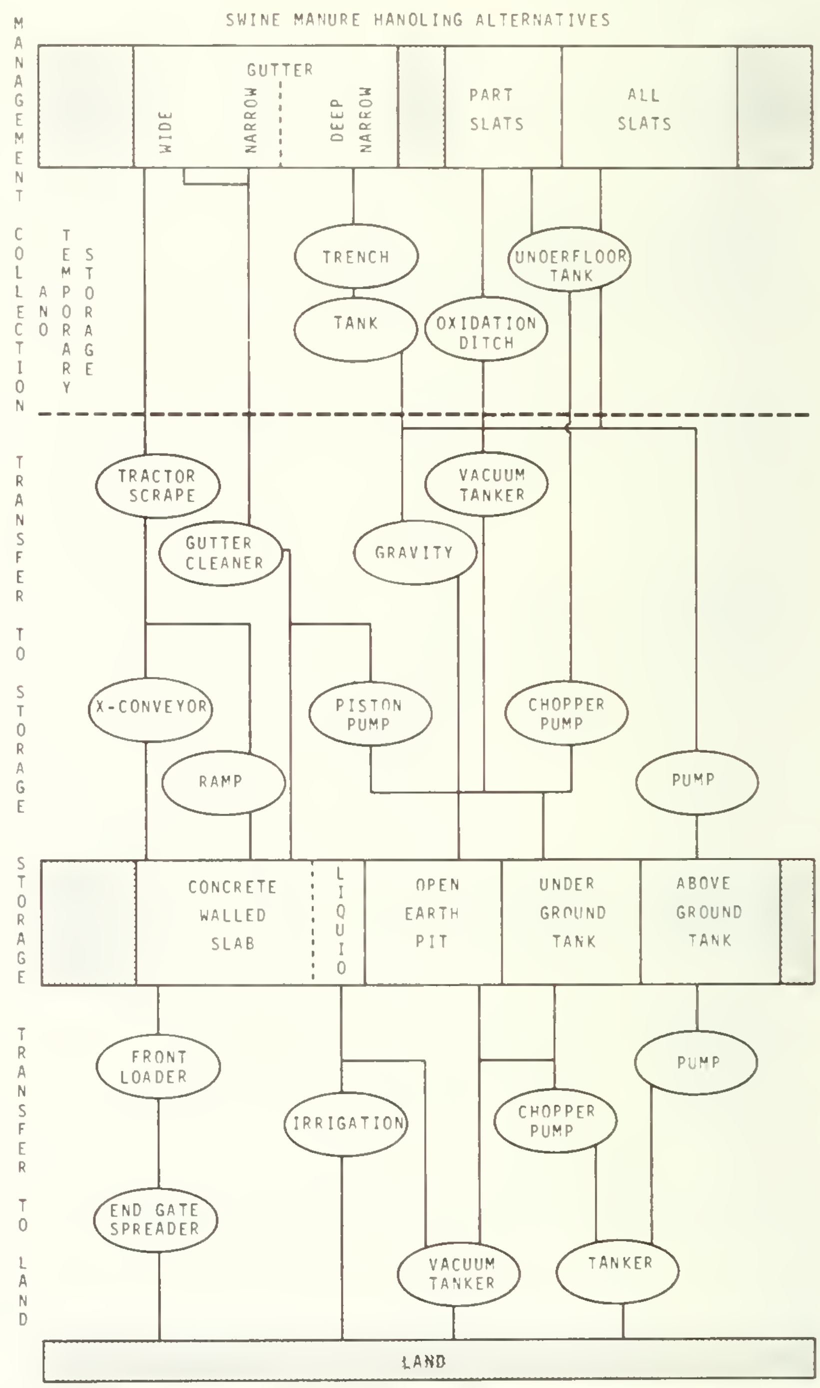


Figure 3.5.11 Simplified network for SPNA of swine manure handling alternatives (from J.R. Ogilvie et al (21))

More frequently, slotted floors cover a collecting gutter, for swine, beef and dairy (see Figure 3.5.1). Gutters may be shallow (about 300 mm clear depth) with a flushing system as described above, or may be deeper to accommodate other liquid transfer systems as follows.

The simplest transfer system is a truck- or trailer-mounted vacuum tanker for unloading the gutters, and for transport to either long-term storage, or directly to field for spreading. Draw-off pipes are permanently installed, leading from outdoors into the gutter bottom at about 8 m intervals. The gutter end of each pipe opens into a small sump below gutter floor level; this maintains a gas-seal to outdoors and permits more complete emptying. Limitations of this system are the small volume of storage under the slotted floors, and the difficulties of transferring manure to long-term storage during cold or wet weather.

Manure is usually flushed out of deep gutters by gravity. One method is to slide a sluice-gate of plywood or steel sheet into fitted grooves near the outlet end of each gutter; when almost full, the sluice-gate is jerked up, releasing accumulated liquid manure. Flushing effectiveness depends in part on the capacity of the channel and piping downstream. Problems with the sluice-gate system include: solids settling and accumulating in the gutter bottom remote from the outlet; slow leaks around the edges of the sluice-gate, resulting in dewatering of the manure remaining; and difficulties in opening larger sluice-gates under liquid pressure.

For typical, free-flowing swine manures a simple plug-valve (Figure 3.5.2, inset) has overcome the last two of these problems.

For beef and dairy manure the sluice-gate and plug-valve systems here described will not give complete and effective emptying. For these, a 'continuous flow' system from Europe is much more reliable. The continuous flow (or 'lip' system) functions at much higher percent solids than other systems described here. Gutter bottoms are made flat and smooth, and a low weir across the outflow end of each gutter holds back a minimum of 150 mm of liquid (water at first, liquid manure when operating).

Figure 3.5.3 shows the continuous flow system, for swine. Manure accumulating in the gutter assumes a surface slope dependant on the manure viscosity and rate of supply, and trickles slowly over the weir. Anaerobic decomposition in the oldest manure at the bottom seems to help lubricate the mass, to maintain flow.

For cattle manure the outlet valve (Figure 3.5.3, item 7) would be too small; use a cascade of wider channels with an overflow weir at each drop. Channel length is determined by manure surface slope and the obvious economy of building gutters as shallow as possible, consistent with reliable self-cleaning. Channel width is limited to 2.4 m or less, due to the possibility of meandering flow and resulting liquid separation in wider channels.

3.5.3.2 Chain-and-flight Conveyors

Bedded manure in swine and dairy barns (either stanchion or free stall) that has a solids content of 15% or higher can be moved to storage areas by chain-and-flight conveyors. These units are designed for slow speed, heavy-duty operation. Electric-drive units are usually 1.1 to 2.2 kW depending on the size of barn to be cleaned. For gutters 355 or 460 mm wide, a single chain with attached flights, typically spaced 460 mm apart, drags the solids to an inclined conveyor or stacker that can either convey the manure directly into a manure spreader or to a concrete apron outside the barn for later removal for land spreading. These units are illustrated in Figures 3.5.12 and 3.5.13. An alternate conveyor is a shuttle-stroke gutter cleaner with flights hinged to fold on the back stroke. The stroke of the rod must be greater than the width of the flights to advance the manure. Typical dimensions are 1980 mm stroke and 1040 mm spacing of flights. These units operate in straight lines only; they usually require cross-conveyors or are used as cross-conveyors to remove the manure to an outside storage pile.

Where parallel aisles up to 3.2 m wide occur as in a free-stall dairy barn, one-way folding scrapers can be attached to continuous cable or chain stretched along the centerlines of both aisles (Figures 3.5.14 and 3.5.15). The aisles may be up to 120 m long. The cable passes around pulleys at the end of each aisle to form a continuous loop. One end of the cable or chain is attached to a motorized reversing drum or sprocket. One pair of scrapers drags manure to the end of the aisle and into a cross-conveyor that takes it to storage, while the cable in the parallel aisle is moving scrapers in folded position in the opposite direction. When the full length of the aisle is traversed, the motorized drum reverses and the second aisle is scraped. The unit can be controlled by a time clock to operate through one cycle, stop, and start again at a later time. The

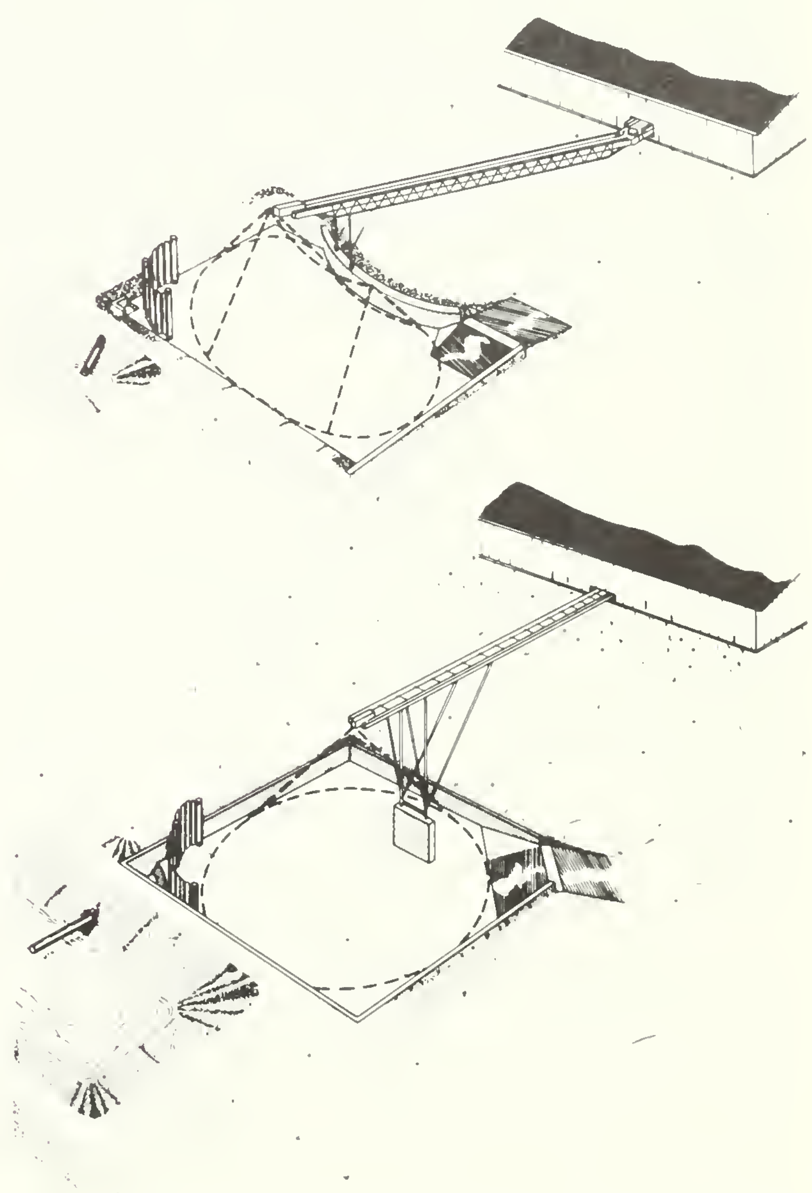


Figure 3.5.12 Curbed storage slab for stacked manure (CPS Plant 2703)

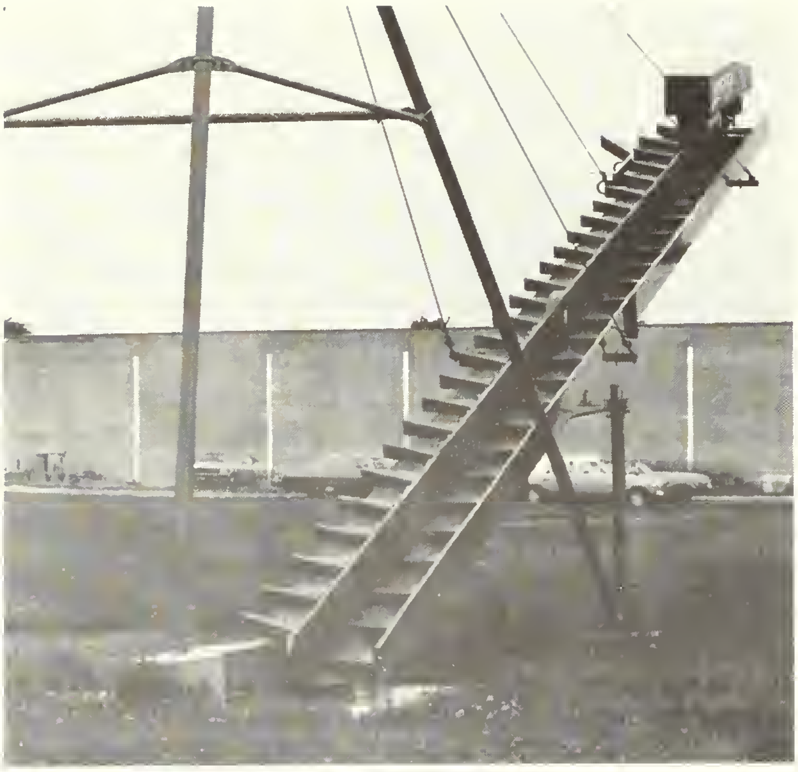


Figure 3.5.13 Typical manure stacker (courtesy Patz company)

Figure 3.5.14 Reversing alley scraper (courtesy Badger Northland Inc.)

speed of travel is slow enough to let cows step over the moving scraper blades.

3.5.3.3 **Tractor Scrapers, Scoops and Forks**

Paved surfaces in dairy barns, holding and exercise areas can be cleaned with scrapers attached to the three-point hitch of a tractor. These units are suitable for thin and thick manure slurries.

Many units can be converted quickly to push or pull. Side plates or wings are required to retain the slurry as the tractor pulls or pushes the manure to storage or transfer conveyor. Widths are available from 1700 mm to 2100 mm to accommodate different alleyway construction. Hard rubber or hardwood skirts and squeegee blades are recommended since these can be replaced when worn (11). The rubber squeegee also reduces wear on the concrete alleyways which quickly become polished and slippery if a steel-edged scraper is used.

Scoops are available usually as attachments to front-end loaders (Figure 3.5.16). Scoops are tilted hydraulically fore and aft for loading, unloading and slurry retention during transport. Typical "break-away" loads are 1400 kg to 2600 kg. Bucket widths range from 1.0 to 1.5 m. If the solids exceed 20%, front-end fork loaders can be used to transfer from piles to manure spreaders. These units are designed to fit standard hydraulic front-end loaders of tractors. Depending on tractor size, these forks may lift up to 800 kg (11). Additional information on front-end loaders is given in Section 2.4.

3.5.3.4 **Plunger-type Manure Pumps**

The transfer of dairy manure from inside the barn to outdoor storage can be accomplished by forcing the manure through a pipe placed underground below the frost line (Figures 3.5.17 and 3.5.18). Advantages are: (a) winter freezing of conveyors and other exposed manure handling equipment is avoided; (b) odor problems can be reduced by formation of an undisturbed crust on the surface of the pile; (c) flies may be reduced if the crust is dry and undisturbed; (d) there may be less loss of liquids; and (e) the fertilizer value will be enhanced since volatilization of nitrogen compounds will be reduced.

Disadvantages are: (a) higher initial cost than conventional systems; and (b) the rate of manure removal is slower than conventional gutter cleaners.

Fortier's (10) investigation of horizontal, vertical and inclined plunger-type pumps, both mechanically and hydraulically powered, revealed the following:

Mechanically-powered units had rectangular plunger sizes of 200 x 200 mm or 200 x 300 mm that operated at 35 to 45 cycles per minute, the length of stroke ranging from 355-460 mm. Hydraulically powered units had plunger sizes ranging from 200 x 200 mm to 495 mm diameter that operated at 2 to 6 cycles per minute, the length of stroke ranging from 910-1200 mm. Electric motors were from 3.7-11 kW. In all cases studied the transfer pipe from pump to manure storage was 300 mm diameter polyethelene or polyvinylchloride and limited to 60 m for semisolid manures and 90 m for semiliquid manures.

A schematic of a mechanically-driven vertical plunger pump and underground pipe to a slurry storage tank is shown in Figure 3.5.18. The storage should be below the

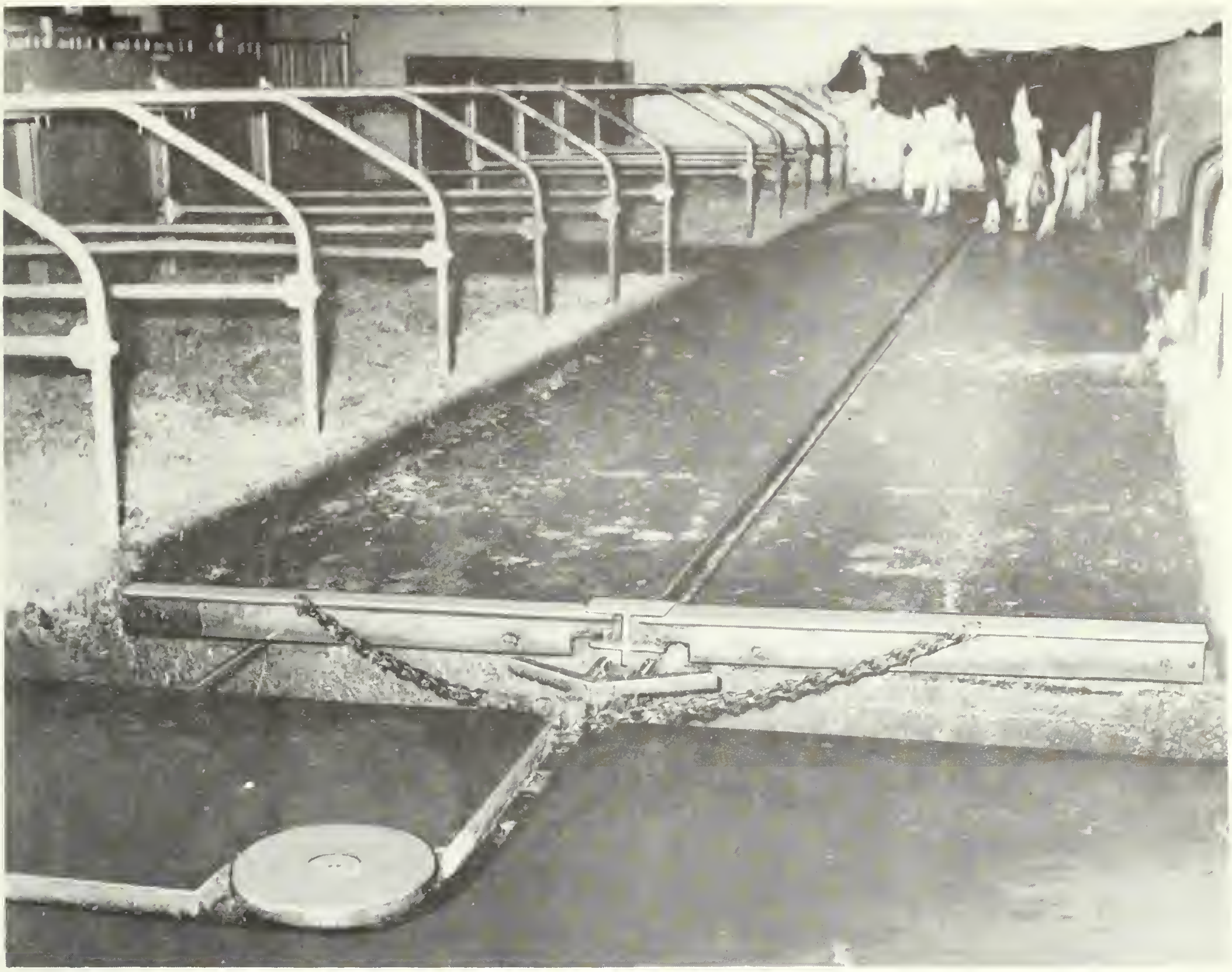


Figure 3.5.15 Folding flight on reversing scraper (courtesy Badger Northland Inc.)

pump, otherwise a check valve at the discharge end of the pipe is advisable.

The rate of manure removal by the pump must be at least as great as the rate at which manure is delivered by the cleaning conveyors in the stanchion-barn gutters or free-stall alleys. If the two units are not matched in capacity the pump hopper will overflow. If the hopper size is increased and the manure contains a significant amount of bedding, bridging over the entrance to the plunger is likely to occur. This will require additional labor and reduce the overall efficiency of the system.

This Quebec study further indicated that the motor size should be at least 5.6 kW since the amperage drawn by a smaller 3.7 kW motor could be double the normal during power strokes. Overheating and shortened bearing life (2000 to 5000 h) will occur. Bridging problems can be minimized by hopper designs with two vertical sides. The manure transfer pipe must be kept below the frost line. Avoid elbows; each 20° elbow adds friction equivalent to 7.6 m of 300 m diameter pipe. Based on 1975 prices, pump costs were found to be 1.5 to 3 times the cost of a chain-and-flight manure stacker.

Finally, these pumps are not necessary for handling typical liquid manure. For dairy manure, however, the

Figure 3.5.16 Tractor and manure scoop (note rear steering for manoeuverability)

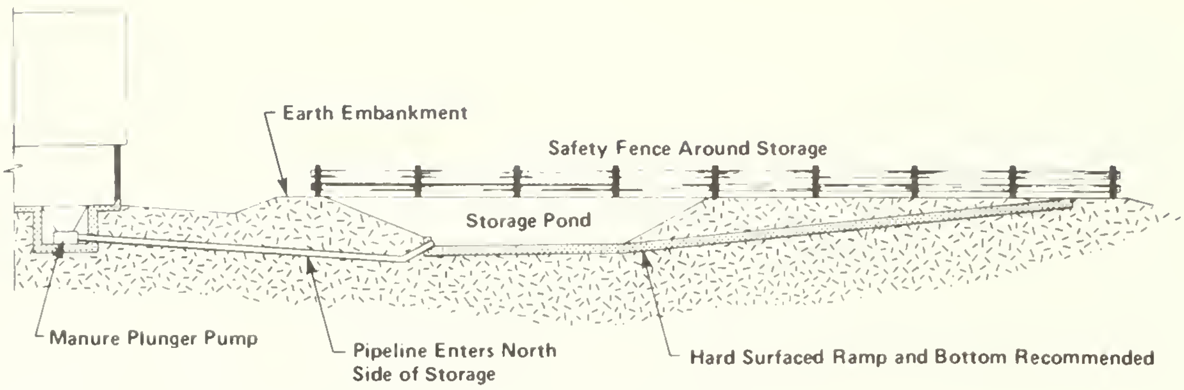


Figure 3.5.17 Manure storage pond using manure plunger pump for loading

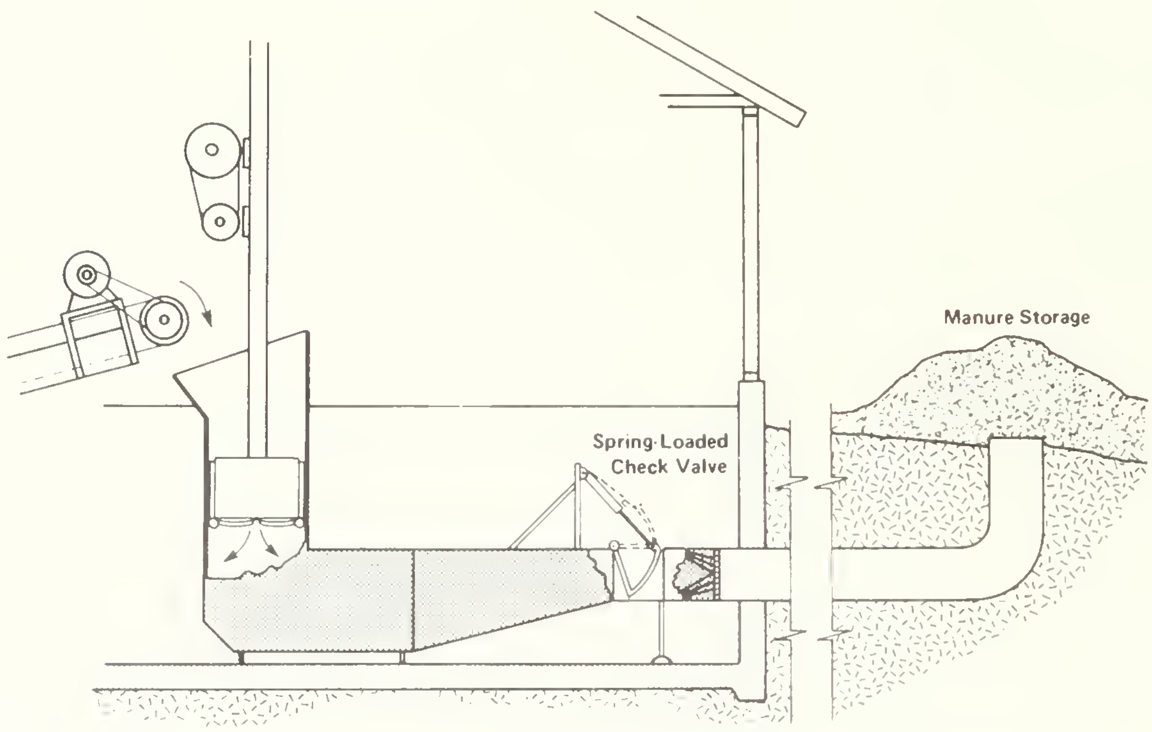


Figure 3.5.18 Schematic of vertical plunger pump used to transfer dairy manure to storage

Figure 3.5.19 Pneumatic pressure vessel for transferring manure to storage tank (courtesy Patz Company)

system solves most cold weather handling problems and can be a good investment.

3.5.3.5 **Pneumatic Transfer**

A steel pressure vessel connected to a manure storage by pipeline can be filled with manure by a tractor scraper or gutter cleaner. When the vessel is closed, compressed air at 100 kPa (15 psi) supplied by a 745 W compressor forces the manure slurry to the storage. The only moving parts in this system are the compressor, the vessel lid, a check valve at the bottom of the tank and another pipeline outlet in the manure storage. A 6400 L pressure tank is shown in Figure 3.5.20 in an excavation to place the lid at the elevation of a paved area to which dairy manure is scraped. Maximum recommended length of 300 mm PVC pipe is 60 m.

3.5.4 MANURE STORAGES

Land spreading animal manures from intensive housing systems on a daily basis is not practical. Therefore, a storage structure is required to collect manure and runoff from open yards or feedlots between periods of land spreading. In most of Canada, this is limited to spring and fall when snow, frozen ground and sensitive crops do not interfere.

Storages can be classed as four types: above ground, covered and uncovered, and below ground, covered and uncovered. Below-ground storage structures should not be buried more than 0.6 m below the high water table to avoid uplift problems when the manure storage is empty. If the tank floor must be lower than 0.6 m below maximum water table elevation, it is better to allow some leakage inwards at the floor-to-wall joints. Construction details for several types of storages are offered by the Canada Plan Service and available from provincial agricultural extension engineers (Figures 3.5.20 to 3.5.23). A commercial steel manure tank is illustrated in Figure 3.5.24. Siting storages to allow for future expansion of the animal production enterprise is important. They should be located for convenient access to fields with tractor and manure handling equipment. Studies in B.C. have indicated that below-ground liquid manure storages will retain slightly more ammonia nitrogen than above-ground storages. Because some segregation of solids occurs, the slurry in liquid manure tanks tends to form a crust. The stored slurry should be agitated with a manure pump prior to emptying. Figures 3.5.25 and 3.5.26 show a tractor-powered manure pump that will agitate and stir the manure slurry in the storage tank as well as transfer the tank contents to field spreaders.

3.5.4.1 **Storage Sizes**

The size of storage should be matched to the average number of type of animals, the number of days of storage required between manure removal and the average precipitation on the storage area during the storage period. Manure storage volume can be estimated from the following relationship:

$$Vs = (Na\ Vm\ t) + Vw \qquad (1)$$

where

Vs = volume of storage

Vm = volume of manure produced per animal per day (see Table 3.5.1)

Vw = Volume of dilution water either as precipitation or water added to improve pumpability of liquid manure (see Figure 3.5.27)

Na = average number of animals housed during storage period

t = storage time in days.

Since construction costs were approximately \$37.60/m^2 uncovered or \$64.60/m^2 covered (November 1976 prices), the volume of dilution water or precipitation added to the storage (Vw) must be minimal.

3.5.4.2 **Storage Construction Features**

All manure storages, whether for solid, semisolid or liquid should be constructed to contain all contaminated waters and to exclude clean runoff water. Storages designed by the Canada Plan Service incorporate such features and

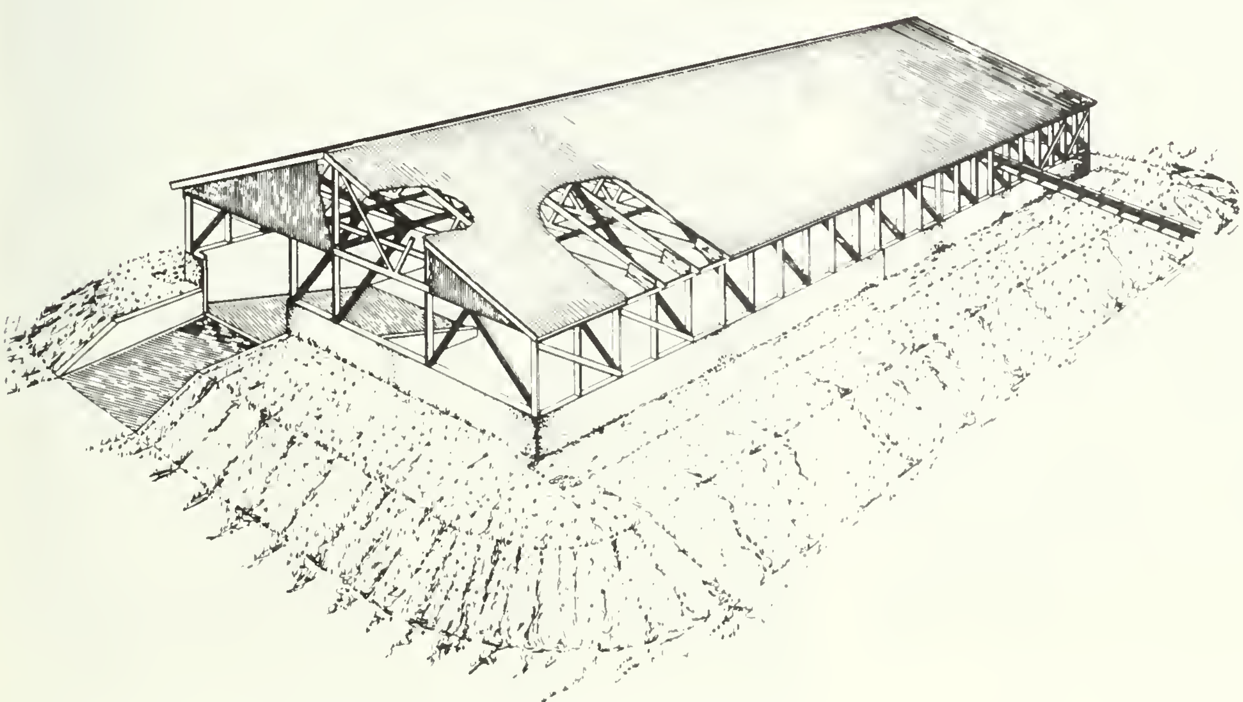


Figure 3.5.20 Rectangular roofed storage for semisolid manure (CPS Plan 2705)

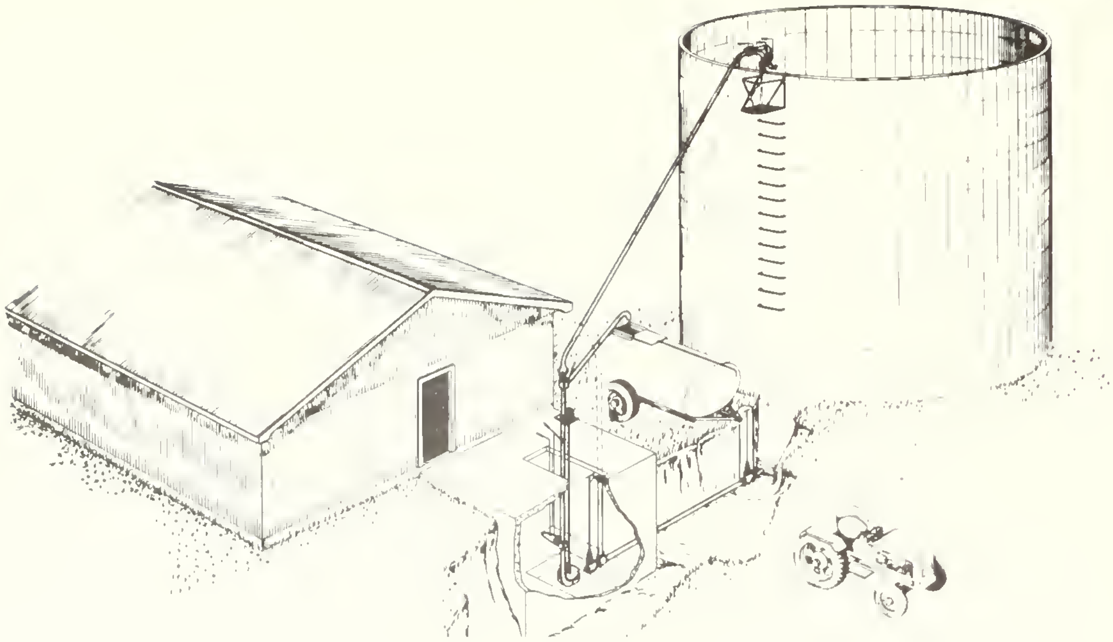


Figure 3.5.21 Above-ground liquid manure silo, tractor PTO-pump system (CPS Plan 3250)

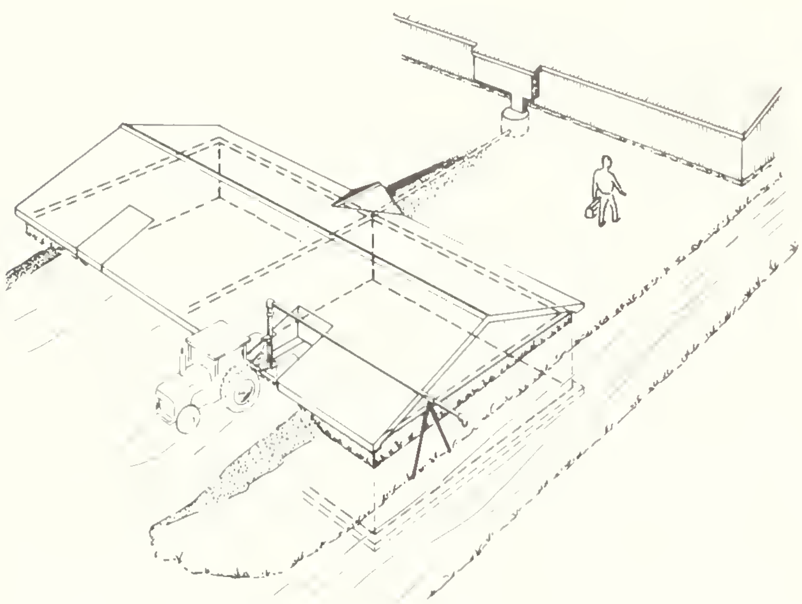


Figure 3.5.22 Rectangular roofed manure tank (CPS Plan 3253)

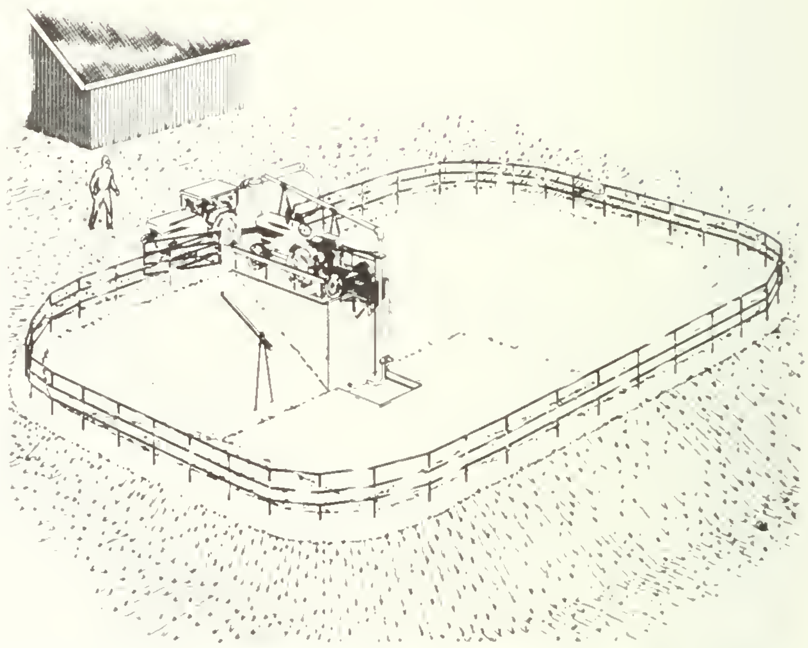


Figure 3.5.23 Clay-lined manure storage pond with dumping dock (CPS Plan 2371)

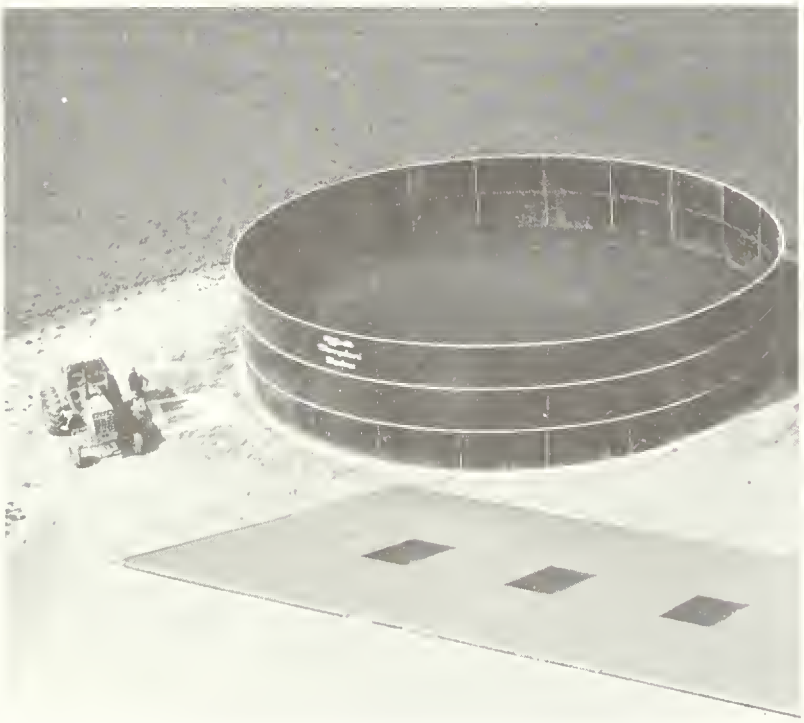


Figure 3.5.24 Slurry storage (courtesy A.O. Smith)

Figure 3.5.25 Tractor-operated manure pump for agitating and manure transfer from above-ground storage (courtesy A.O. Smith)

they should be followed closely during construction. Additional information on storage design is included in Section 6.2 of this manual.

3.5.5 SOLID-LIQUID SEPARATION

The separation of manure slurries into stackable solids and pumpable liquids is sometimes a useful step for a satisfactory manure handling system. Some current and potentially useful methods and equipment are sedimentation screens and centrifuges. The objective of these solid-liquid separation methods is to produce either (a) a clarified effluent for recycling as flush water or for land spreading by sprinkler irrigation or (b) concentrated solids for land spreading or further drying.

3.5.5.1 Sedimentation

Overflow rate and detention time are design parameters that have the most influence on total suspended solids (TSS) and chemical oxygen demand (COD) removal efficiencies. Sobel (25) reported that dilution was very important to the settling rate of both dairy and poultry waste. Overflow rate determines the surface area and detention time determines the depth of a sedimentation chamber.

Moore et al. (20) found that a minimum of 1.0 min detention time for settling should be used for closed recycling systems. The maximum detention time can be taken as 10 min depending upon the storage of the flushing media. For outdoor feedlots subject to highly variable rainfall and snow melt, the design detention period can be taken as 100 min. Shutt el al. (24) found that about 4 hours detention time for swine oxidation mixed liquor achieved 90% TSS removal. Studies in Britain (2) indicated that the use of flocculating agents such as ferrous sulphate (2 to 3 mg/kg), ferric chloride (0.75 mg/kg) or calcium hydroxide (5 mg/kg) doubled the solids settled from the slurry in a given time period compared to untreated slurry. Periodic removal of settled solids which can be land spread is necessary as is the collection of floatable solids. Recent studies by West (30), however, indicated that coagulating agents were not effective when used on the liquid fraction from mechanical screens.

3.5.5.2 Stationary Screen

This is a stationary sloping screen with special horizontal slots so arranged as to be essentially self cleaning. Diluted manure flows down the full width of the screen so that solids are retained and slide down the upper surface. Shutt et al. (24) found that for handling swine manure from finishing areas the best performance occured with a flow rate of 11.25 L/(s·m^2) of screen area or 0.08 L/(s·m) of screen width for 1.5 mm wide screen opening. At this loading rate about 6% of incoming solids were retained by the screen. Microbial growth occurred on the underside of the screen and regular brushing was required to maintain satisfactory operation.

3.5.5.3 Liquid Cyclone

A liquid cyclone works on the same principle as an air cyclone used to remove particulate material from an air stream. The liquid enters tangentially into a cylinder which has a matching cone at the bottom. Settleable solids move down the inside surface of the cone under the influence of centrifugal and gravitational forces. Clarified liquid escapes through a concentric pipe that enters through the closed top of the cylindrical section and extends down to the join between the cylinder and cone.

Shutt et al. (24) report a 76 mm diameter, 6 degree apex cone cyclone increased total suspended solids from 0.5% to 9% (an 18-fold increase) when the liquid cyclone was operated with a 3.2 mm diameter underflow nozzle at a

Figure 3.5.26 Portable manure agitation and transfer pump (courtesy Badger Northland Inc.)

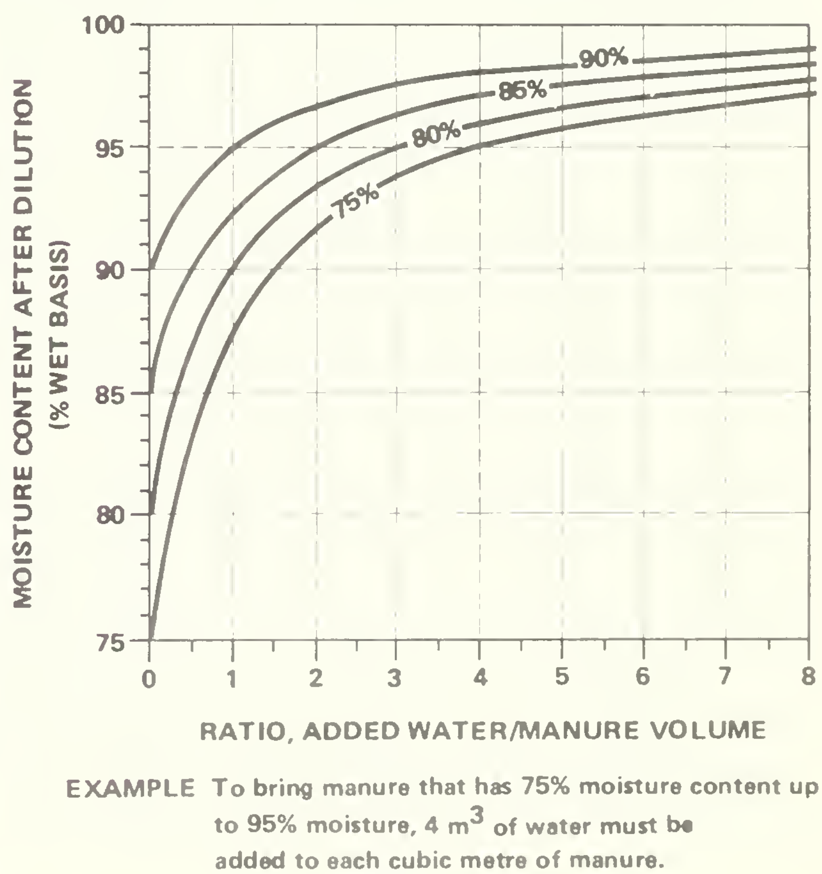


Figure 3.5.27 Volume of dilution water required to change the solids concentration of liquid manure

flow rate of 1.5 L/s. Hepherd and Douglas (14) report that studies at the West of Scotland Agricultural College on oxidation ditch mixed liquor from piggeries showed solids concentration of 5% could be produced from 1% solids inflow. Using a two-stage process, 8% solids could be produced. At this time the method does not seem practical for most farms.

3.5.5.4 **Centrifuge**

A typical commercial centrifuge consists of a horizontal conical bowl rotated at 4750 rpm with an inner auger conveyor scroll, rotated at 4780 rpm. This difference in rotational speed causes a continuous movement of material through the unit as illustrated in Figure 3.5.28 (f). With a typical throughput of 112 kg/h, a solids fraction containing 26% dry matter and a liquid fraction with 3.2% dry matter was achieved. This relatively low output was combined with a high power requirement and high capital cost (2).

3.5.5.5 **Vibrating Screens**

Vibrating screens (Figure 3.5.28 (d)) with various reciprocal and rotary motions are available for screening wastewater. Shutt et al. (24) tested one such unit and found the optimum manure loading rate to be 6.80 $L/(s \cdot m^2)$ of screen with 0.39 mm openings. The solids on the screen were concentrated to 16.4% on a wet basis. In terms of BOD and COD removal, however, the stationary screen was found to have a higher efficiency.

3.5.5.6 **Filter Presses**

The removal of water from manure by presses of various types produces a stackable solid (70-75% water) that can be spread onto land prior to tillage and a liquid that contains up to 85% of the N, P and K. This liquid can be used for flushing manure trenches or can be land spread by tank spreader or portable irrigation system. Several manure filter presses are now developed, such as the Farrow Separator and Gascoigne Slurry Separator in Great Britain and the Surge TRU in North America.

Equipment for removal of coarse material from typical dilute domestic sewage has not been found satisfactory for separating solids and liquids in manure slurries since manures have much higher dry matter content.

Generally, an efficient separator must run for long periods with little attention or maintenance. It should be fed by gravity from the source of slurry and should be capable of handling large solid objects together with straw and hay without blockage or damage to the machine.

Figures 3.4.28 (c) and (e) are diagrams of two designs that hold promise for on-farm installations. The brushed-screen press with a throughout of 773 kg/h of 11.3% dry matter produced a stackable solids fraction of 16.6% dry matter. The rotary screen press converted cow slurry with 9.7% dry matter to a stackable solids fraction of 22.6% dry matter. Experiments with screw presses and belt presses showed these to be uneconomic or to have very low efficiencies compared to the screen presses. Table 3.5.2 gives a summary of separator performance for screening cattle slurry (2).

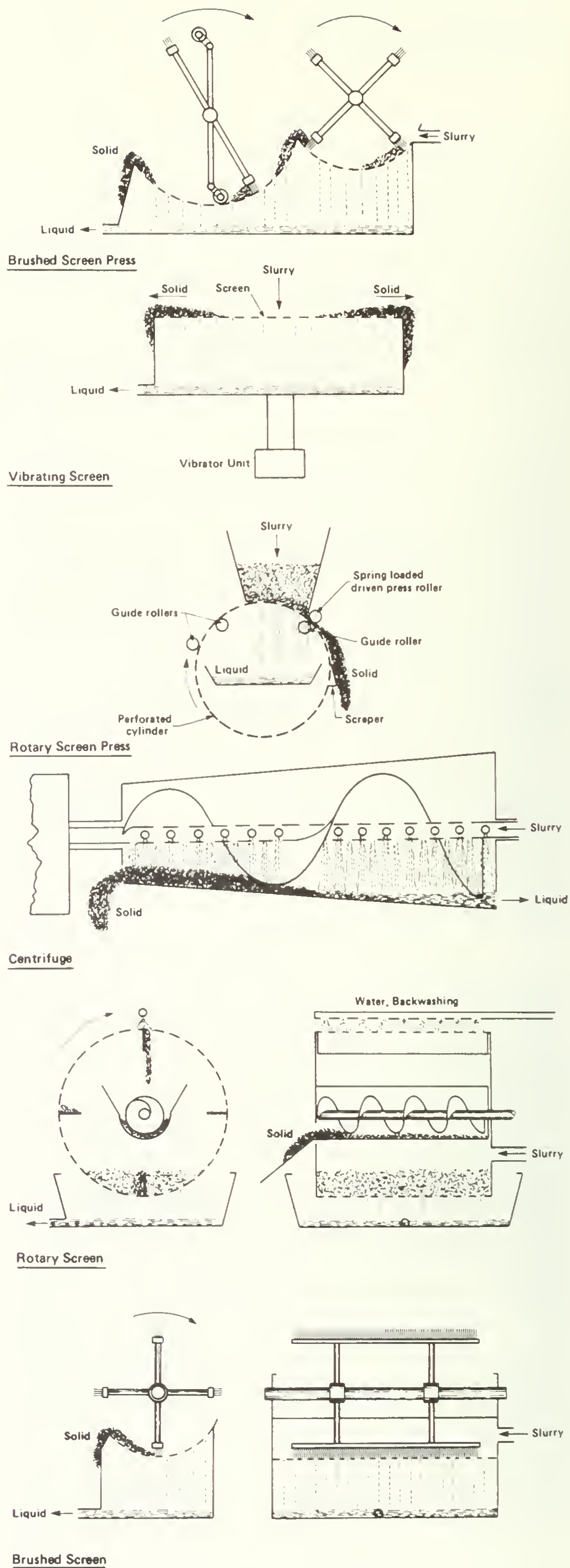


Figure 3.5.28 Solid-liquid separation devices (from Agricultural Research Council, London, U.K. (2))

3.5.5.7 **Floor Heating**

When heated floors are employed for rearing young stock, such as the nursery and weaning area of swine units, in pullet-rearing buildings of poultry laying enterprises and in broiler buildings, a secondary benefit will be dried manure and litter. This product is generally odor free and can frequently be sold to market gardeners. However, this method of drying is not justified for other livestock.

3.5.5.8 **Forced-air Drying**

Studies by Bressler (5) in Pennsylvania and by Hamilton (12) in B.C. have shown that unheated air can be used to reduce the moisture content of poultry manure from 76% to 25% in deep-pit poultry buildings. Continuously operating 500 mm diam. fans equipped with 190 W motors are hung below the cages at 9 m intervals. Starting with an empty pit, the fans are mounted 0.6 m from the floor and raised as the manure piles up (Figure 3.5.29). All fans are directed to maintain air circulation around the pit. Energy consumption is approximately 4.5 kWh per day per fan. Drinkers must be selected and maintained for minimum water spillage. Canada Plan Service plan 5211 shows a similar system, but with fans suspended under the walkways to simplify servicing (see Figure 3.5.30).

3.5.5.9 **Heated-air Drying**

Heated-air drying is usually used with poultry manure to produce pasturized organic protein (POP) or marketable organic fertilizer. Rotary drum and shaking screen driers have proven reliable for handling this product. Initial experimentation indicated that a profitable product could be produced. Recent and likely increases in energy costs indicate this may become a less profitable alternative to the waste management problem. Additional details on heated-air driers can be found in Section 3.1.

3.5.5.10 **Incineration**

Incineration is not a total disposal method since 10 to 30% of the dry matter in manure will be left as ash. If animal manure cannot be land spread or treated in other ways, then as much water as possible must be removed prior to incineration. Dehydration, natural drying or dewatering should be considered as a first step. The calorific value of air-dried poultry manure is 11 800-13 700 kJ/kg (5100-5900 Btu/lb) (26). Not all of this heat can be used for preliminary drying, however, since the waste gases contain considerable heat energy, part of which could be recovered with suitable heat exchangers. If incineration temperatures cannot be maintained above 700°C (1300°F), combustion will not be complete and air pollution will occur. All incinerator installations should meet National Fire Protection Association standards as well as local requirements.

Incineration is expensive. No useful byproduct is obtained and energy is used to support combustion and to remove and dispose of the resulting ash. However, it may have to be considered for unusual situations such as in research facilities experimenting with highly-contagious diseases.

TABLE 3.5.2 Summary of Separator Performances with Cattle Slurry

Machine type	Machine Setting	Slurry		Solids		Liquid		General Condition of Solids
		Type	DM g/kg	Output kg/h	DM g/kg	Output kg/h	DM g/kg	
Rotary screen	Screen mesh with 4.8 mm apertures fitted. No backwash with water	Cattle; diluted	56	1170	80	1170	30	Wet; not stackable[1]
Ditto	Ditto; but with 360 kg/h backwash	Cattle; diluted	55	1210	75	1490	27	Ditto
Brushed screen	3.2 mm round-hole screen fitted	Cattle; undiluted	71	530	87	370	48	Wet; not stackable
Ditto	Ditto	Cattle; diluted 1:1	37	490	91	2210	25	Wet; fairly free draining
Brushed screen with roller press attachment	Ditto	Cattle	96	Not recorded	185	Not recorded	45	Stackable, moist
Vibrating screen 460 mm	1.5 mm mesh screen fitted	Cattle	101	Ditto	152	Ditto	102	Wet; fairly free-draining
Vibrating screen 1130 mm	120 B.S.S. screen fitted	Oxidation ditch liquid from cattle slurry	12	270	94	2160	8	Wet; fairly free-draining, stackable
Rotary screen press	3 mm screen	Cattle	97	162	226	658	70	Stackable, moist; very easily handled
Horizontal solid bowl centrifuge	Set for highest DM in solids	Cattle; diluted about 1:1	61	112	260	770	32	Stackable, moist; very easily handled
Ditto	Set for lowest DM in liquid	Ditto	71	530	149	1000	30	Just handleable as a solid

[1]"Stackable" — forms a stable heap without retaining walls
From: Reference (2)

3.5.6 BIOCHEMICAL ALTERATIONS

Aerobic microorangisms are those that derive chemical energy by using oxygen as the ultimate electron acceptor. The electron flow in aerobic oxidation of organic compounds is through the dinucleotides NAD (nicotinamide adenine dinucleotide) and FAD (flavin adenine dinucleotide), cytochrome b, c and a and cytochrome oxidase, to oxygen the final electron acceptor. In anaerobic cells, the electron flow does not occur through the cytochrome system but energy is conserved in the secondary organic products. Aerobic treatment then consists of systems designed to replenish dissolved oxygen in water containing organic wastes. Microbial decomposition of organic matter requires relatively long time periods and non-biodegradable and microbial solids still prevent the effluent from being acceptable for discharge to streams.

3.5.6.1 **Naturally Aerated Lagoons**

Organic matter is decomposed through aerobic oxidation with the oxygen supplied from mixing and photosynthesis of algae present in the surface zone of a lagoon containing waste water. Continuous mechanical movement of the liquid by wind and temperature effects is necessary to maintain aerobic conditions.

These lagoons can handle loading rates of up to 5.5 g BOD/($m^2 \cdot d$) and produce effluents of 10-20 mg BOD/L if algal growth is constantly removed (18). These lagoons require adequate sunlight, wind action, proper temperature, and available land. Many areas in Canada probably cannot provide all these.

The key microorganisms in naturally aerated lagoons are bacteria and algae. Sunlight provides the energy necessary for algal development. Oxygen released by the algae becomes available for heterotrophic bacteria. For BOD removal to be effective, carbonaceous material in the algae must be removed constantly from the lagoon since Co_2 used for algal growth is continually supplied by the atmosphere and the incoming water. Therefore, the net increase in organic matter must be removed constantly from the system.

The production of 1.0 g of algal cell mass produces about 1.6 g of O_2. One g of carbon (C) will produce about 1.9 g of organic matter, 1 g of N will produce about 12 g of organic matter, and 1 g of P will produce about 75 g of organic matter as algal cells. Because algae are about 55% C, 9% N and 1% P, nitrogen and phosphorus rarely are limiting in manure treatment systems.

Since sunlight is the energy source for algal growth, naturally aerated-lagoons are limited to 0.9 to 1.5 m deep to permit maximum penetration of sunlight. Light intensities over 320 lx (30 ft-c) are required for any measurable algal growth.

Temperature effects on the degradation rate are similar to those of other microbial systems and are approximated from

$$K/K_{20} = \Theta(t-t_{20}) \qquad (2)$$

where K is the reaction rate at temperature t (°C) compared to the reaction rate K_{20} at t_{20}, or 20°C.

Θ = 1.072 (best fit to available data). The range of t for which the above equation is valid is 3°C to 35°C (15). This relationship has not been tested for livestock manures and is not likely to be valid below 10°C.

Lagoon loading rates of 2.2-4.5 g BOD/(m^2.d) (20-40 lb BOD_5/ac/day) have shown satisfactory performance in the northern U.S.A. for low-strength sewage. However, with the high-strength, low volume manure produced by most livestock operations, very large areas are required. For example, for 380 m^3/d of dilute manure having a BOD_5 of 1000 mg/L and 2.2 g BOD/($m^2 \cdot d$) organic loading rate,

Figure 3.5.29 Forced-air drying of poultry manure in deep-pit buildings (courtesy B.C. Ministry of Agriculture)

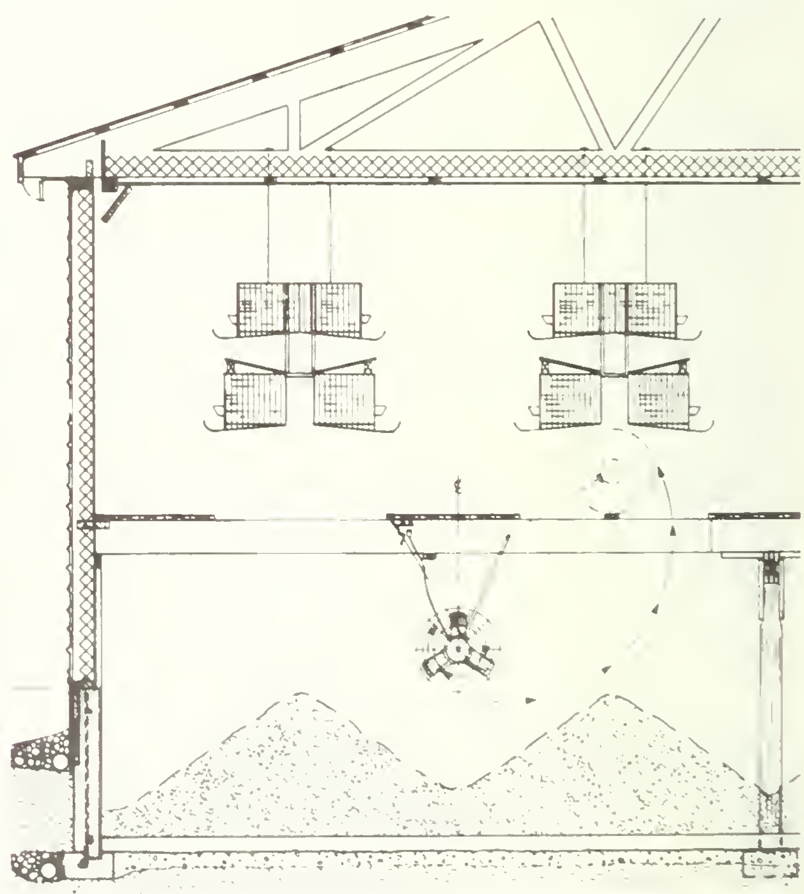


Figure 3.5.30 Forced-air drying of poultry cage manure (CPS Plan 5211)

the lagoon area required would be 17 ha. For this area the evaporation rate could be greater than the daily liquid input.

3.5.6.2 **Mechanical Aeration Systems**

The performance of aerobic lagoons can be improved by introducing oxygen into the lagoon contents by mechanical methods. Two basic methods are floating or surface aerators and submerged pipelines or diffusers supplied with compressed air. The major advantage of these systems is odor control since for high-strength manure the remaining BOD level of the output will be too high for disposal methods other than land spreading. Table 3.5.3 compares several aeration systems.

3.5.6.2.1 **Diffuse Aeration**

To reduce the surface area of aerobic lagoons, air or pure oxygen can be mixed artificially with dilute manure. A diffused air system is designed to force compressed air into the stored liquid through porous ceramic material or perforated pipes at depths up to 4.5 m. The rising air bubbles create turbulence and mixing. The rate of oxygen transfer is dependent upon the area of the air-water interface created. Biological growths tend to clog small openings in diffusers. To reduce maintenance problems diffusers with large openings have been developed but adsorption efficiencies will be low (about 3-10%).

3.5.6.2.2 **Turbine Aeration**

A turbine-type mixer combined with compressed air forced through a diffuser immediately below the turbine placed at significant depth into the liquid will increase greatly the air-water interface. The air supply can be decreased when the oxygen demand is low while the turbine keeps the solids in suspension. Average oxygen transfer efficiencies are in the order of 15-20%.

These units can supply high oxygen demands beyond the capabilities of surface aerators. Since they are not greatly influenced by liquid level changes and icing problems they are viable alternatives for many regions in Canada.

3.5.6.2.3 **Surface Aeration**

Surface aerators mechanically create turbulence at the liquid surface with a series of partially submerged rotating blades. As a result, air is entrained and mixed with the liquid in the lagoon. A unit designed for farm use is shown in Figure 3.5.31.

These aerators are generally slow speed with high pumping capacities. Gas-liquid contact is increased by

TABLE 3.5.3 Mechanical Aeration System Comparison

System	Oxygen Transfer	Solids Suspension	Advantages	Limitations
Diffused aeration	Transfer depends on bubble size; fine bubble diffusers higher than large bubble diffusers.	Basin design requires special attention with diffuser location critical for good suspension. Not good for use in deep basins.	Quiet operation. Flexibility through variable gas rates, enabling tailoring of oxygen transfer to system loads.	Fine bubble diffusers are subject to plugging problems, thus often requiring air filtration. Diffused air systems require properly-designed long, narrow basins which may increase construction costs.
Submerged turbine aerator	Intermediate efficiency below surface but higher than diffused air.	Can handle very high solids concentrations in deep tanks of 6 m or more water level. Full power is applied near basin bottom.	High degree of flexibility in oxygen transfer is available through speed changes and a variable gas rate. Solid suspension in deep basins is good. Not limited by area available. Can be used in high-rate systems or for basins designed for maximum use of premium land.	Higher installed power due to lower oxygen transfer efficiencies. Submerged piping cannot be installed on floating platforms for shallow lagoon operation.
Surface aerators	Generally highest of systems described.	High flows produce good suspension of biological solids. Lower impellers or combined units using submerged aeration design techniques are required for deep basins.	High oxygen transfer efficiency. Elimination of submerged piping. Can be float-mounted for lagoon systems. Requires little or no standby equipment for multiunit installations. Submergence adjustment allows changes in oxygen transfer to suit varying loads in the system.	Requires sufficient area for proper aeration. High-rate systems applied in deep basins may have insufficient surface area to utilize full power.
Combined surface & submerged turbine aerators.	Generally design dependent on split between surface aerator and submerged turbine.	Generally good and adjustable for use in deep basins through proper design.	Aerator speed and gas rate changes are flexible. Advantage of turbine features for good solids suspension in deep basins. Partial oxygen transfer can be maintained with blowers shut down.	Submerged piping required. Combined aeration generally requires a higher installed hp.

From: *Pollution Practice Handbook*, 1975, P.M. Cheremisonoff and R.A. Young, Ann Arbor Science Publishers, Ann Arbor, Mich.

splashing the liquid into the air, dispersing air into the liquid, and generating a high level of surface turbulence. Oxygen transfer is related to the volume flow rate as follows:

$$R = \frac{L\,(DO_2 - DO_1)}{10^6} \quad (3)$$

where R = oxygen transfered, kg/h

L = liquid flow through the aeration zone, kg/h

DO_2 and DO_1 = average dissolved oxygen concentration leaving and entering the aeration zone respectively.

In general, the O_2 transfer range of surface aerators is 1.2-2.4 kg/(kW.h) under standard conditions (28).

At least five types of surface aerators are currently in use:

1. plate type, a rotating plate with vertical blades that create vigorous surface agitation;

2. updraft type, a propeller that pumps and splashes large quantities of surface liquid with relatively low pumping energy;

3. downdraft type, a propeller or rotating blades that draw air down into a turbulent zone (Figure 3.5.31);

4. brush type, a horizontal revolving shaft to which a series of blades are attached and the whole unit mounted across a ditch or raceway such that the blades extend 75-225 mm below the liquid surface (Figure 3.5.32);

5. inclined propeller for mounting in oxidation ditch (see Figure 3.5.33).

Types 1 and 3 usually are mounted on a frame with floats, to move up and down with changing liquid levels. Type 4 is used for oxidation ditches either outside or under slotted floors.

Many lagoons equipped with surface aerators are in fact facultative lagoons (Section 3.5.6.6). The mixing zone of the aerator does not extend to all parts of the lagoon, and, hence, solids will settle. These eventually have to be removed and disposed by land spreading or some other approved manner.

3.5.6.3 **Activated Sludge**

Activated sludge refers both to a process and the biological mass that results from the aerobic treatment of organic matter. The system consists of an aeration unit for aerobic treatment and a sedimentation tank in which the solids settle out of the liquid. The system is usually plug flow (first in, first out) since untreated waste plus return sludge enter the aeration tank at one end and move as a unit to the discharge point. Settleable solids in raw waste may be removed in a primary sedimentation unit. Dissolved oxygen concentration in the aeration unit should be kept above 0.5 to 1.0 mg/L.

High oxygen demand occurs at the inlet and tapers off along the length of the aeration unit; aeration can be tapered in approximately similar fashion. Inlet to outlet demand ratios are approximately 5:1 or 10:1 with inlet demand in the order of 100 mg O_2/(L·h).

These units are used more widely in treating cannery and other food processing plant wastes than for animal manure. BOD removal can be 90% or better depending on the solids removal in the final effluent discharge. Animal manure generally has higher and more variable

Figure 3.5.31 Downdraft floating aerator (courtesy Fairfield Engineering and Manufacturing Co.)

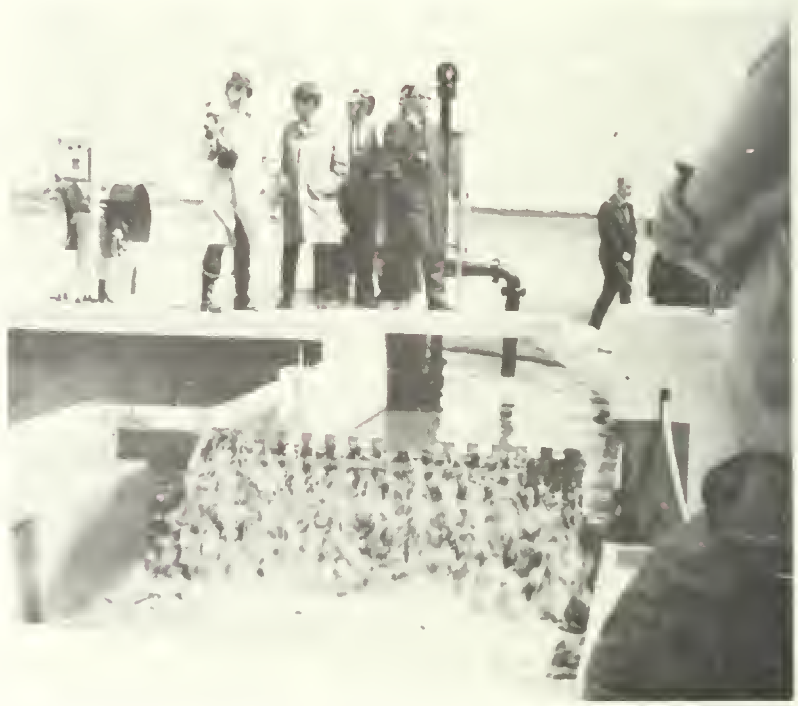


Figure 3.5.32 Brush-type aerator for oxidation ditch

Figure 3.5.33 Inclined propeller for oxidation ditch mixing and aeration (courtesy Fairfield Engineering and Manufacturing Co.)

concentrations, therefore it can be more readily treated by the following modifications.

3.5.6.3.1 Contact Stabilization

Raw manure and activated sludge are held for ½ to 1 hour in a sedimentation tank where organic matter is absorbed onto the activated sludge floc. It is necessary to remove hair, straw and undigested feed before mixing the liquid fraction with the floc. Currently there is limited experience with high-strength manure.

3.5.6.3.2 Complete Mixing

Incoming manure enters the aeration tank through one or more inlets to achieve a complete mixing of the entire contents within a few minutes. The oxidation ditch beneath animal pens is a type of complete mixing system. Table 3.5.4 contains design recommendations for oxidation ditches handling animal manure.

3.5.6.3.3. Extended Aeration

Extended aeration provides a high degree of treatment when long detention periods are possible. Solids are settled in a sedimentation tank and recycled to the mixing basin. Typical operating characteristics are 4000 to 6000 mg/L of mixed liquor suspended solids and a solids retention time of about 20 days. BOD removals of 90% are possible if the suspended solids are also separated from the effluent. The reduction in sludge volume could be an advantage where time or land for final disposal is limited. For most farm situations, the complexities of operation are not likely warranted.

3.5.6.4 Composting

Composting is a microbiological process that requires intimate mixing of solid organic matter in small particles with oxygen and moisture. This allows microorganisms to grow, if given time to complete the process.

Two stages occur, stabilization and maturation. The stabilization phase is marked by a temperature rise to the thermophilic range of 55-70°C. Rapid multiplication of bacteria occurs and pathogenic organisms are destroyed. When the energy source is depleted the temperature slowly drops to ambient. At this point the maturation phase occurs, marked by further slow degradation of organic matter by fungi until volatile solids are reduced by about 50%. For optimum process conditions, 50-60% moisture (wet basis) is required.

Composting of livestock manures can be carried out by mechanically turning it in windrows or bins. Figure 3.5.34 shows a self-propelled, windrower mixer turning beef manure. Steam rising from the material indicates the high temperatures obtained.

Dairy, beef, swine and poultry manure can be composted more effectively by adding ground corn cobs, wood shavings, straw, or sawdust. These large particles improve air movement, reduce the moisture content and add carbon to improve the nutritional balance for bacterial growth. The proportion of carbon to nitrogen (C/N ratio) is near optimum at 30:1 for rapid composting.

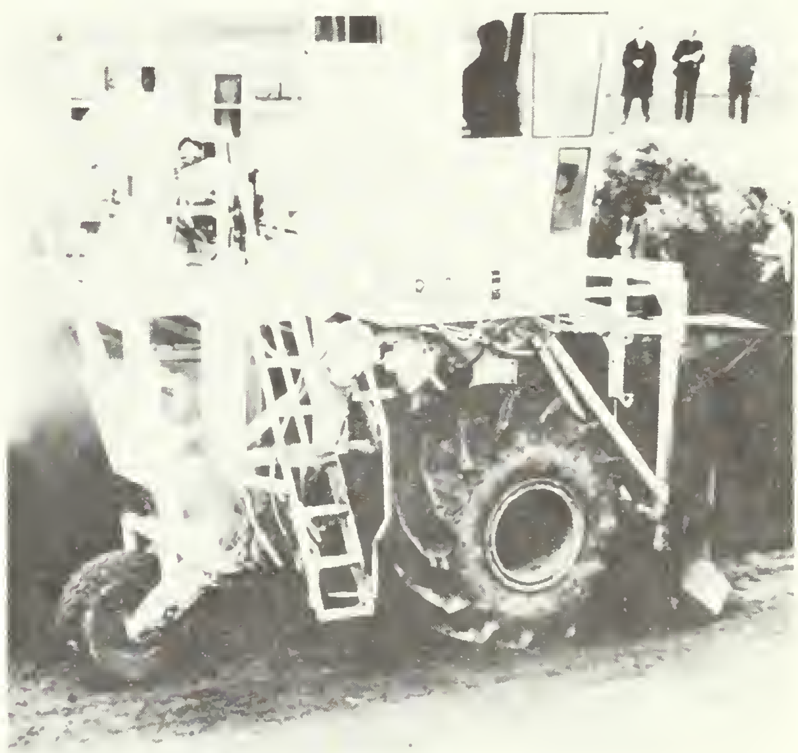


Figure 3.5.34 Composting beef manure

TABLE 3.5.4 Design Recommendations for In-the-building Oxidation Ditches

Animal	Weight/Unit (kg)	Weight/Unit (lb)	Daily BOD_5/Unit[1] (kg)	Daily BOD_5/Unit[1] (lb)	Daily Required Oxygenation Capacity per Unit[2] (kg)	Daily Required Oxygenation Capacity per Unit[2] (lb)	Number of animal Units[3] per Unit Length of Rotor (m)	Number of animal Units[3] per Unit Length of Rotor (ft)	Ditch Volume/Unit[4] (m^3)	Ditch Volume/Unit[4] (ft^3)	Daily Power Requirement (kWh/Unit)[5]
Sow with litter	170	375	0.36	0.79	0.72	1.58	52	16	0.67	23.7	0.83
Growing pig	29	65	0.06	0.14	0.13	0.28	299	91	0.12	4.2	0.15
Finishing hog	68	150	0.15	0.32	0.28	0.62	134	41	0.27	9.6	0.33
Dairy cow	590	1300	1.0	2.21	2.0	4.42	20	6	1.87	66	2.33
Beef feeder	408	900	0.61	1.35	1.22	2.70	33	10	1.13	40	1.42
Sheep feeder	34	75	0.02	0.053	0.05	0.11	755	230	0.05	1.6	0.06
Laying hen	2	4.5	0.01	0.0198	0.02	0.0396	2133	650	0.02	0.6	0.021

[1]Use specific production data when known
[2]Twice the daily BOD_5
[3]Based on 25.5 lb of O_2 per ft of rotor per day
[4]Based on 30 ft^3 per lb of daily BOD_5
[5]Based on 1.9 lb O_2 per kWh
From: (Jones, D.D., D.L. Day and A.C. Dale, *Aerobic Treatment of Livestock Wastes*, Bull. No. 737. Univ. of Illinois, Urbana, Agricultural Experiment Station in cooperation with Purdue Univ., Revised Bulletin, April, 1971)

Compost is more useful as a soil conditioner than as a fertilizer. Therefore, handling costs limit its usefulness for fertilizing farm fields and it is more likely to be feasible for market gardens and home gardens in suburban areas.

3.5.6.5 **Liquid Thermophilic Processes**

Experimental work has indicated that livestock manure can be stabilized by mixing in air and agitating the liquid slurry to encourage the growth of thermophilic bacteria. This growth begins at 45°C. Because the oxidation process is an exothermic reaction yielding 33-42 J per gram of carbon oxidized, there is an accelerated biological growth that results in a temperature rise of the slurry into the most-active thermophilic range, 55-65°C. This elevated temperature and high biological activity reduce digestion time of manure to about 15 days.

Figure 3.5.35 illustrates a commercial processing system. The final product has no obnoxious odor, nor has the processing phase, and the final product has an acceptable palatability for monogastric and ruminant animals. The elevated temperatures have been shown to destroy salmonella and E. Coli (9). The pH will change from 5.6-6.7 initially to a final level of 9. Table 3.5.5. lists several significant parameters of the system (29). Solids level in the slurry should be adjusted to 5-7% total dry matter.

3.5.6.6 **Facultative Lagoons**

Facultative lagoons have aerobic conditions in the surface layer and anaerobic conditions in both the bottom layer and the settled solids. Design loadings are in the order of 5.6 g BOD/(m^2·d) and effluent BOD concentrations may drop to 20-40 mg/L under ideal temperature and light conditions (18). This BOD level is mainly due to bacterial and algal protoplasms that have developed from the incoming organic wastes.

As organic material enters it settles to the bottom of the lagoon and undergoes anaerobic fermentation. This fermentation reduces the sludge volume if temperatures are over 7°C. Fermentation products rise to the surface zone where sunlight furnishes the energy for algal growth. This growth releases oxygen which is utilized by heterotrophic bacteria. Oxygen requirements are frequently supplied by surface aerators. If the zone of influence of a surface aerator does not include the entire

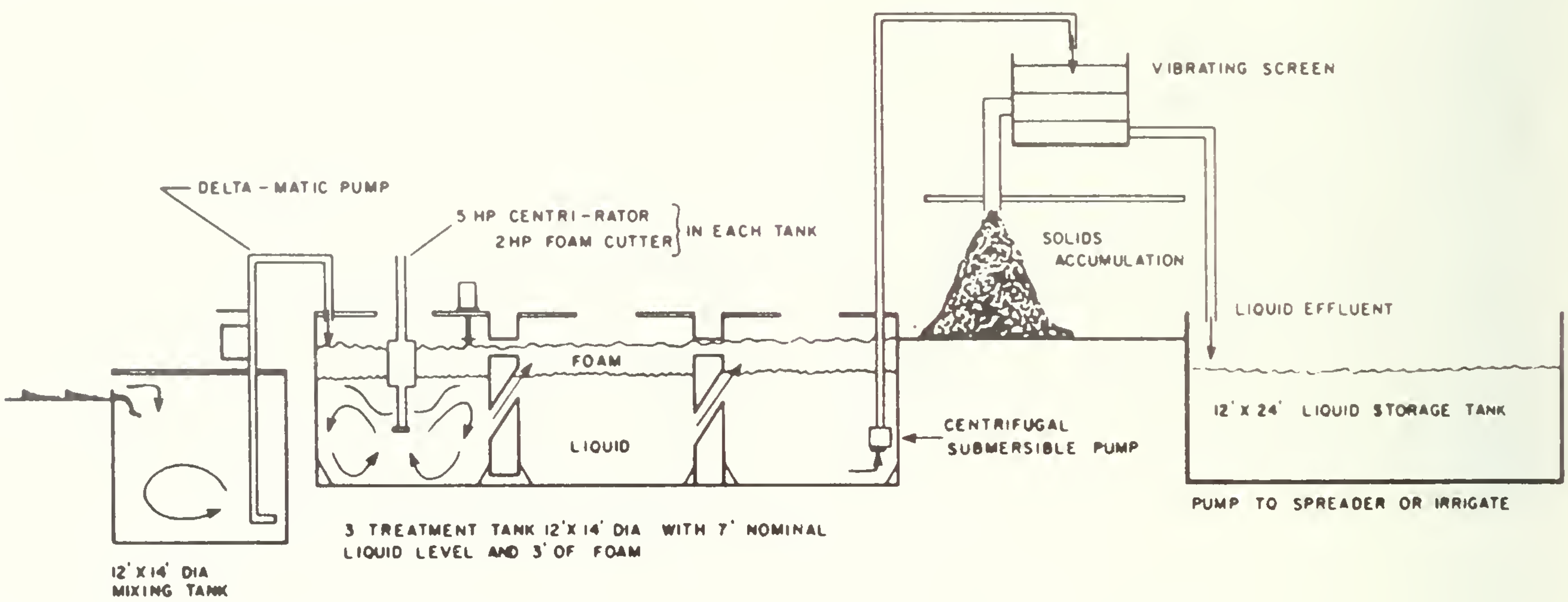


Figure 3.5.35 Thermophilic processing of manure

TABLE 3.5.5 Licom II FS - Dairy Cattle Waste - Averages of Data Taken[1]

Parameter	Raw Cattle Waste	Mixing Tank	Aerated Waste Concentration	Aerated Waste Reduction[1]	Screened Liquid Concentration	Screened Liquid Reduction[1]	Screened Solids
Quantity, liters/day	3800[2]	7300[2]	6450-7300[2]	2-10	5160-5850[2]	22-32	1280-1460[2]
pH	7.5-8.0	7.1-7.8	8.5-9.3	—	8.5-9.3	—	8.5-9.3
TS, percent WB	15.0	7.8	6.0	24	4.0	50	17.5
TVS, percent of TS	86.0	86	85	26	77	55	94.0
COD, mg/L	25,200	10,800	5750	47	3050	72	—
BOD_5, mg/L	16,800	6100	4000	35	1750	71	—
Total coliforms/mL	100,000,000	—	—	—	0	99+	—
TKN, mg/L	3800	2540	1800	29	1820	—	1670
NO_3, mg/L	370	560	250	—	242	—	260
NO_2, mg/L	21	26	22	—	25	—	21
Odor threshold dilution number	5770	—	—	—	191	32:1	—

[1]Percent reduction from mixing tank contents—percent reduction of TS and TVS based on quantity, i.e. TVS reduction always greater than TS reduction.

[2]Represents best estimate from data available—not physically measured

From: Reference (29)

volume of the lagoon then facultative conditions will prevail. Because there is an annual variation in sludge accumulation as temperatures change between summer and winter the discharge from these lagoons should be land spread to avoid potential pollution of receiving water courses.

3.5.6.7 **Anaerobic Treatment**

Most naturally occurring organic matter can be fermented or digested anaerobically. The predominant microorganisms are anaerobic, deriving their energy from complex organic compounds using oxidizing agents (electron acceptors) other than oxygen, such as sulphates and nitrates. The complex organic compounds are broken down to simpler organic fatty acids (volatile acids) and then converted to gaseous end-products such as methane and carbon dioxide.

Carrying the above process to completion results in methane and carbon dioxide production, with a substantial reduction in solids that are stabilized. When COD values exceed 4000 mg/L anaerobic fermentation has been reported to be more economical than aerobic treatment for the stabilization of wastes (8).

There are several reasons for considering anaerobic processes such as: (a) higher BOD and COD loading rates than are feasible with aerobic treatment; (b) useful end-products such as methane and stabilized organic matter; (c) alteration of water-binding characteristics for easier sludge dewatering; (d) solids volume reduction. Factors to be considered when evaluating anaerobic digestion are loading, mixing, solids retention time, temperature, nutrients and buffering capacity.

Increasing concentrations of volatile acids will inhibit methane producing bacteria. Therefore the influent must be alkaline (capable of buffering) to counteract the production of volatile acids. Ammonia-nitrogen concentrations above 3000 mg/L also can inhibit the anaerobic process (19). This can occur if the pH becomes too high since ammonium ions and dissolved ammonia are in equilibrium as:

$$NH_4^+ \rightleftharpoons NH_3 + H^+$$

The higher the pH the more the equilibrium shifts to the right. Hence anaerobic reactions occur in a restricted pH range.

Growth of anaerobic microorganisms is lower than that of aerobic microorganisms, hence the minimum solids retention time (SRT), which can be found by dividing the volatile solids in the system by the volatile solids leaving the system per day, will be much longer than for aerobic systems. Reductions in BOD_5 of 80-90% and in solids concentration of 50% are possible. Effluent leaving the treatment system is still a pollutant and if not land spread requires further treatment before discharge into a water course.

3.5.6.7.1 **Anaerobic Lagoons**

Anaerobic lagoons are similar to aerobic lagoons in that both are impoundment units for holding wastes. The loading rate on anaerobic lagoons however is such that surface reaeration and photosynthetic activity cannot take place. The destruction and stabilization of organic matter is the objective. A gradual buildup of settled solids will occur and periodic solids removal is required. The anaerobic lagoon is a simple treatment system that will produce a decrease in BOD and COD when temperature in the lagoon exceeds 13-14°C (3). In addition, it is an economical holding unit for manure prior to land spreading.

Anaerobic lagoons require less land area than an equivalent aerobic lagoon since they can be much deeper and more heavily loaded. Depths to 4.6 m (15 ft) are practical provided that groundwater remains below the deepest point. A relatively dilute liquid layer will exist above settled solids at the bottom. A floating scum or deep crust may occur depending on the nature of the manure. Anaerobic lagoons are essentially single stage, unmixed, unheated digestors. Loadings of 30-200g $BOD_5/(m^2 \cdot d)$ and 2-5 kg $VS/(m^3 \cdot d)$ have been used. Lagoon sizes can be estimated then from the characteristics of various manures listed in Table 3.5.6. If anaerobic lagoons become overloaded, an increase in volatile acids occur which lowers the pH and inhibits any growth of the anaerobes. Methane production ceases and the lagoon merely becomes a storage basin.

When an anaerobic lagoon is in biological balance the odor level is minimal. However, manure with a sulphur content will produce hydrogen sulphide. Since other noxious gases can be produced if imbalance occurs, such as during and after clean out or during the onset of warm weather in the spring, these lagoons should be located away from built-up areas. The bottom and sides of the lagoon should be sealed with clay or bentonite to avoid contamination of groundwater. Organic matter is removed from the lagoon by discharge to another

TABLE 3.5.6 Anaerobic Treatment of Agricultural Wastes[1]

Waste	Temperature (°C)	VS Process Loading kg/(m³·d)	VS Process Loading lb (ft³·day)	Process
Beef cattle	23	1.6-6.4	0.1-0.4	Single stage
Poultry	—	2.7-4.9	0.17-0.31	Single stage
Dairy	—	2.1-3.5	0.13-0.22	Single stage
Poultry	35	1.4	0.088	Single stage
Duck	37	to 2.4	Up to 0.15	Single stage
Dairy bull	—	3.8	0.24	Single stage
Swine	—	3.8	0.24	Single stage
Poultry	—	2.9	0.18	Single stage
Dairy	—	1.6-2.9	0.1-0.18	Single stage
Swine	35	4-8	0.25-0.50	Single stage

[1]From: Reference (18)

retention basin or to land spreading, by gas production and by periodic removal of accumulated sludge. Gas production can be 0.5-0.6 m^3/kg of biodegradable solids entering.

During periods of warm weather, 60 to 90% BOD removal may occur but the resulting effluent quality still will not be acceptable for discharge to surface waters. Therefore, land application or a further aerobic treatment unit will be required. To bring about a quick reestablishment of equilibrium in the lagoon, clean-out should be carried out in late spring or early summer.

3.5.6.7.2 **Methane Digesters**

Methane digesters are used widely for treatment of municipal sludge. Farm-sized digesters for manure have been in use in parts of Europe, Asia and Africa. Since microorganisms that are methane formers are most effective at temperatures of 30 to 40°C, further investigations are required to establish reliability for cold Canadian conditions. Currently research is being conducted in Manitoba by Lapp et al (17). Operational criteria established by Lapp (16) are: (a) the addition of active digesting material to a new digester accelerates the start-up time; (b) nutrient balance is usually adequate from manure but excess ammonia retards methane production; (c) volatile solids (VS) loading rates of 4 kg/(m^3·d) for a digester gave maximum yields of gas from liquid swine manure; (d) retention time of 6 to 20 days is required depending on the nature of the manure, operating temperature, and degree of agitation by the mixer; (e) the mesophilic range of 25-35°C is considered optimum for Canadian conditions; (f) the pH must be kept high, and sufficient alkalinity maintained to buffer volatile acids, to provide effective operation; (g) some form of mixing is required, either mechanical or gas bubbles to keep the bacteria in contact with their food supply; (h) the level of total solids must be maintained between 4 and 16%.

Theoretical gas production for manure is given in Table 3.5.7. Ideal conditions such as 35°C digester temperature and continuous loading are required to approach these values under full-scale production. Typical gas composition is 65-70% methane and 30% carbon dioxide. Storage of gas can be provided by an inverted container floated within a slightly larger tank containing water to form a gas seal. The calorific value of the gas is dependent on the amount of carbon dioxide and water vapor present. Typical values will be 6 to 7 kWh/m^3. Since methane and air can combine to form an explosive mixture, it is necessary to ensure that all parts of the system are gas tight, and compressing the gas into storage should be avoided (23).

3.5.6.7.3 **Pyrolysis**

Pyrolysis is the chemical change brought about by heat. The process involves destructive distillation in a closed reactor devoid of oxygen. Studies (31) of pyrolysis of manure indicate that the heating value of gases from dried beef cattle manure was about 4400 kJ/kg (1900 Btu/lb) of total solids, poultry manure yielded about 3800 kJ/kg, and swine manure about 3250 kJ/kg. White et al. (33) has estimated 2.3-3.5 MJ/kg (2-3 million Btu/ton) of dry cattle feedlot manure can be recovered to produce a gas with a thermal content of 11-15 MJ/m^3. At the present time the economics indicate that this system would be feasible only for large units treating in excess of 136 t/day of manure.

3.5.7 REMOVAL AND LAND SPREADING

Land remains the most economical and appropriate treatment of animal manure. Inorganic fertilizers also may be necessary to provide a balanced source of plant nutrients. The nutrient content of animal manures may be a determining factor in the quantity applied. Since crop production, runoff, transfer to groundwater and volatilization of nitrogen represent the removal of nutrients, the supply and removal of these nutrients must balance to minimize a nutrient contribution to groundwater.

Manure application rates must be related to climate, rainfall patterns, soil type, crop production, nutrient composition of manure and required frequency of application. Local public health and pollution control regulations must be considered before final recommendations on land spreading can be made. Table 3.5.1 gives quantities of NPK contained in fresh animal manures. Additional recommendations are contained in the Canada Animal Manure Management Guide (6).

Four categories of equipment are available for land spreading animal manures. The particular type of equipment selected will depend on the solids content of the manure, trafficability of the soils receiving manure, climatic conditions and availability of associated equipment and facilities. Much of the information presented in Sections 3.5.7.1 to 3.5.7.3.2 is based on an Engineering Division BCMA 1977 report on manure spreaders.

3.5.7.1 **Closed-tank Wagons**

Tractor-operated tank wagons are suited to handling slurries with limited bedding. Attachments include pumps, agitating augers, soil injectors or adjustable splash-plates for surface application.

TABLE 3.5.7 Gas Output From Animal Manure

Type of Manure		Gas Output		Residence Time in Digester (days)
With Bedding	Without Bedding	L/kg organic matter	ft^3/lb organic matter	
Cattle		315	0.04	117
	Cattle	210	0.09	20
Swine		415	0.19	115
	Swine	300	0.14	10
	Poultry	300	0.14	20

From: Reference (23)

3.5.7.1.1 Auger-load, Tank-type Spreader

Auger-load, tank-type spreaders require a loading ramp into a below-ground manure storage (Figure 3.5.36). Because the spreader is backed into the stored slurry, these units are usually restricted from travelling on public roads. Capacities are 3-7.5 m^3. Spreading rates are controlled by varying forward speed, PTO speed, and flow valves operated either manually or hydraulically. Power requirements are from 30 kw for a 3.8 m^3 load to 45 kW for a 7.5 m^3 load.

Figure 3.5.36 Auger-load, tank-type spreader (courtesy Engineering Division, B.C. Ministry of Agriculture)

3.5.7.1.2 Top-loading, Pump-filled Tank-type Spreader

Top-loading, pump-filled, tank-type spreaders are used with liquid or pumpable slurries containing minimal bedding. Spreading patterns are generally good, and result from the use of an operated impeller discharge that can direct the flow to either side or to the rear of the spreader. Power requirements are 37-45 kW for a 5.7 m^3 load to 60-67 kW for a 11.4 m^3 load. The larger spreaders are usually equipped with tandem axles and balloon tires.

3.5.7.1.3 Vacuum-load, Tank-type Spreader

Vacuum-type tanks are similar to the top-loading tank except that they are equipped with a vacuum pump for self-loading from a manure storage (Figure 3.5.37). A PTO-powered rotary vane-type pump creates a vacuum inside the tank for loading and a pressure inside for unloading. Intake and outlet ports can be operated manually or hydraulically. Capacities range from 2.8 m^3 requiring 30 kW to 11.4 m^3 requiring 60-67 kW. Loading and unloading rates average 1.1 m^3 per minute. Soil injectors (Figures 3.5.37 and 3.5.38) can be added to reduce odor, nutrient losses, and polluted runoff. Tractor speeds are about 4.8 km/h and the injector applies approximately 12 L per metre of trench. This application rate however should be determined on the basis of allowable application rates for nitrogen.

Bosma et al. (4) have shown the interrelationship between the length of field receiving slurry, the working width, forward speed and pump capacity. The discharge capacity is given by

$$q = \frac{m \cdot a}{3.6 \times 10^3} \quad (4)$$

where q = discharge rate, m^3/s

m = application rate, m^3/ha

and a = rate of coverage, ha/h.

The forward speed is given by

$$v = \frac{a}{0.36\ w} \quad (5)$$

where v = forward speed, m/s

a = rate of coverage, ha/h

and w = working width, m.

The number of tanker loads is given by

$$z = \frac{m}{c} \quad (6)$$

where z = number of tankers

c = capacity of tanker, m^3

Finally, the length of field that would empty the tanker on one round trip is given by

$$d = \frac{10^4}{2wz} \quad (7)$$

where d = length of field, m.

Using a 6 m^3 tanker, the total power requirement including tillage will be 4 to 7.5 kW/m^3 of slurry. Time required by men and machines is 2 to 6 min/m^3 of slurry handled. On rolling land, manure should be injected along contour lines to prevent it from running down the slope. This type of equipment cannot be operated on stony soils or where the height of field crops greatly exceeds the axle clearance of tanker and tractor.

Figure 3.5.37 Vacuum tank-type wagon equipped with soil injector (courtesy Engineering Division, B.C. Ministry of Agriculture)

3.5.7.2 Open-tank Wagons

Open-tank wagons are adaptable to a wide range of manures ranging from high to low solid content.

3.5.7.2.1 **Top-loading, Hopper-type Spreader**

Top-loading hopper-type spreaders are suitable for slurries containing little straw or wasted hay since this material will clog the bottom auger. Filling can be accomplished by most types of tractor front-end loaders or the wagon can be backed into a manure tank for filling with an auger or impeller pump. The top of the tank is equipped with a ledge or lip to minimize spillage of manure. Some makes spread manure from the rear with a PTO-driven impeller, others spread from the front. Power requirements vary from 30 kW for a 3.8 m^3 load to 45 kW for a 7.6 m^3 load.

3.5.7.2.2 **Chain-flail, Tank-type Spreader**

Chain-flail tank-type spreaders (Figure 3.5.39) can be loaded by pumps, tractor or self-propelled bucket or fork-lift equipment, elevators, conveyors, or gravity systems. They can handle manures ranging from high solids to fairly liquid materials. Twenty to forty chains may be mounted on a central shaft in the tank. The shaft rotates at 300 to 1000 rpm throwing the manure by centrifugal action for about 6 m to either the right or left side of the tank. Rear discharge units are also available as shown in Figure 3.5.40. These units achieve a good spreading pattern and are very effective at breaking up manures with high solids content. Power requirements vary from 45 kW for a 4.5 t load to 67 kW for a 9 t load

Figure 3.5.38 Soil injection attachments (courtesy Pearson Bros. Company)

Figure 3.5.39 Side discharge, chain-flail, tank-type spreader (courtesy Engineering Division, B.C. Ministry of Agriculture)

Figure 3.5.40 Rear discharge, chain-flail, tank-type spreader (courtesy Engineering Division, B.C. Ministry of Agriculture)

3.5.7.3 **Wagon-type Spreaders**

Wagon-type spreaders are used for manures with added bedding such that there is little free liquid. Capacity may be expressed in two ways according to ASAE Standard S324 (1). Heaped capacity is the volume in m^3 (ft^3) with the manure stacked 380 mm (15 in) above the upper beater, while the struck-level capacity is measured to the top of the sides or flareboards. Wagons may have a capacity of 2.3 to 10 m^3.

3.5.7.3.1 **Conventional Box-type Spreader**

Conventional box-type spreaders were designed to handle manure with bedding (Figure 3.5.41). For the more semi-solid manures, hydraulically-operated end-gates are recommended. Spreaders may be obtained with single or tandem axles, single or multiple beaters for manure distribution and chain-and-slat apron conveyors in the bottom of the wagon to transport manure to the end-gate. Power requirements vary from 30 kW for a 5.6 m^3 load to 56 kW for a 11 m^3 load.

3.5.7.3.2 **Hydraulic Push-out, Box type Spreader**

A hydraulic push-out, box-type spreader is designed for semisolid manures. The chain-and-slat apron is replaced with a hydraulically-operated front end-gate. Spreading rate is controlled by the rear end-gate position and the ground speed. A reasonably high degree of operator skill is required to obtain uniform spreading. Power requirements vary from 37 kW for a 5.6 m^3 load to 56 kW for 11 m^3.

3.5.7.3.3 **Spreader Capacity**

Manure spreader capacities are expressed in several different units of volume. Solid manure has traditionally been expressed in bushels both for a "heaped" capacity or a "struck" capacity. Figure 3.5.42 was developed by the B.C. Ministry of Agriculture to assist in converting from one set of units to another for comparison.

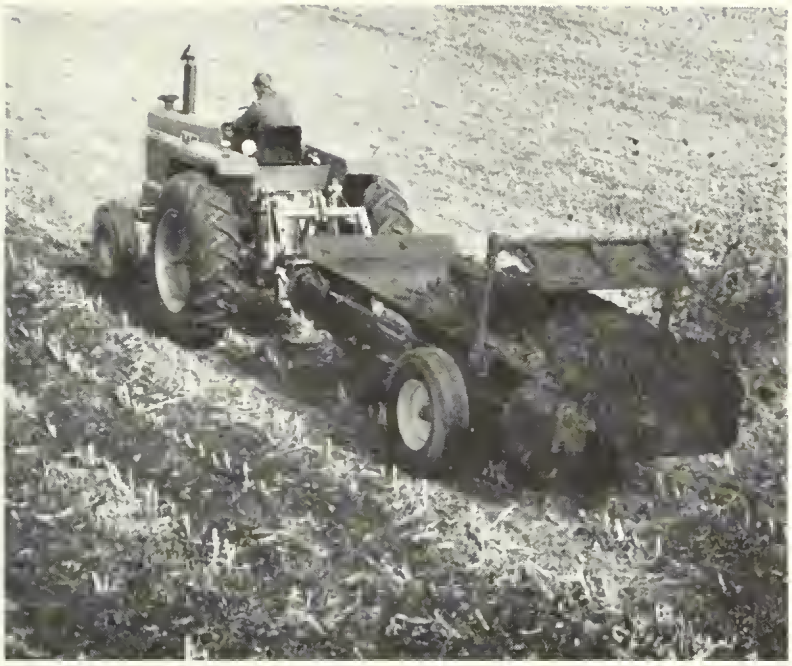
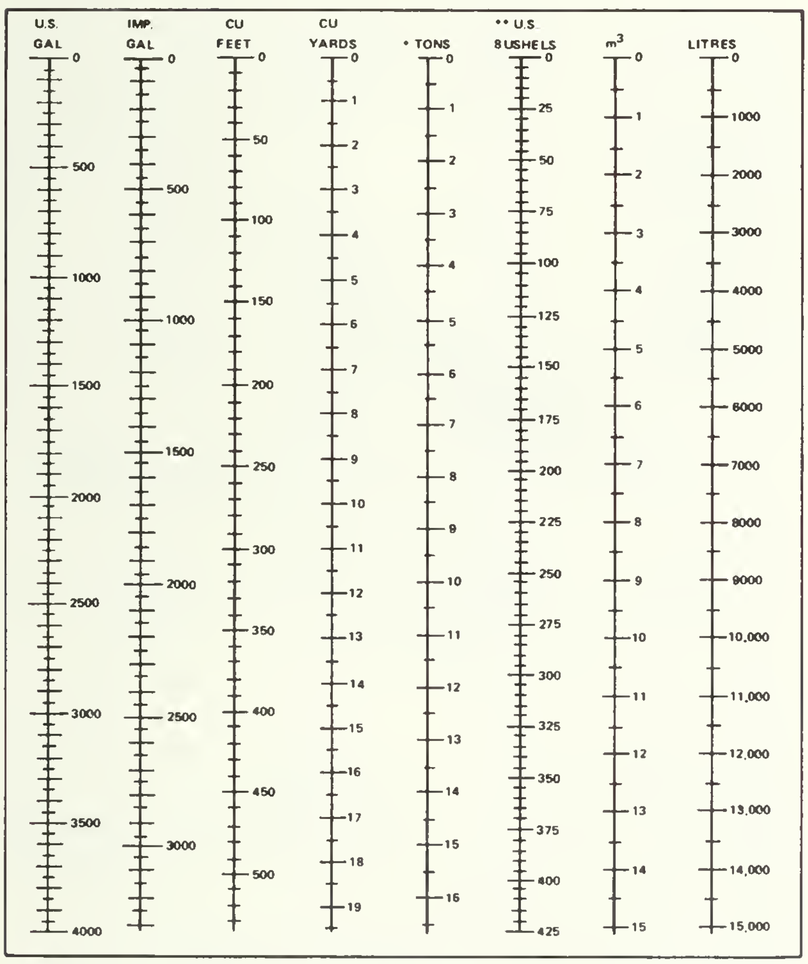


Figure 3.5.41 Conventional box-type spreader (courtesy Badger Northland Inc.)



* ASSUMES A DENSITY EQUAL TO THAT OF WATER (62·4 lb/cu ft)
** THE TERM "BUSHEL" IS MORE OFTEN USED TO REFER TO SOLID MANURE THAN TO SLURRY, CHECK TO SEE WHETHER A "HEAPED" OR "STRUCK" CAPACITY IS INTENDED.

Figure 3.5.42 Manure spreader capacity conversion chart (courtesy Engineering Division, B.C. Ministry of Agriculture)

3.5.7.4 Time Requirements for Land Spreading by Tank Wagon

One of the major considerations that the designer of a manure management system must include is the time available for land spreading at different periods of the year. This means that the size and number of manure spreaders must be matched to the distance to the fields receiving manure, and the size of manure storage which in turn is related to the number and type of animals. Figure 3.5.43 combines actual time and the size of manure storage along with the size of spreader to provide a determination of total hours to empty the storage. An indication of the distribution of elapsed time for various operations in the process is obtained from Figure 3.5.44 (22).

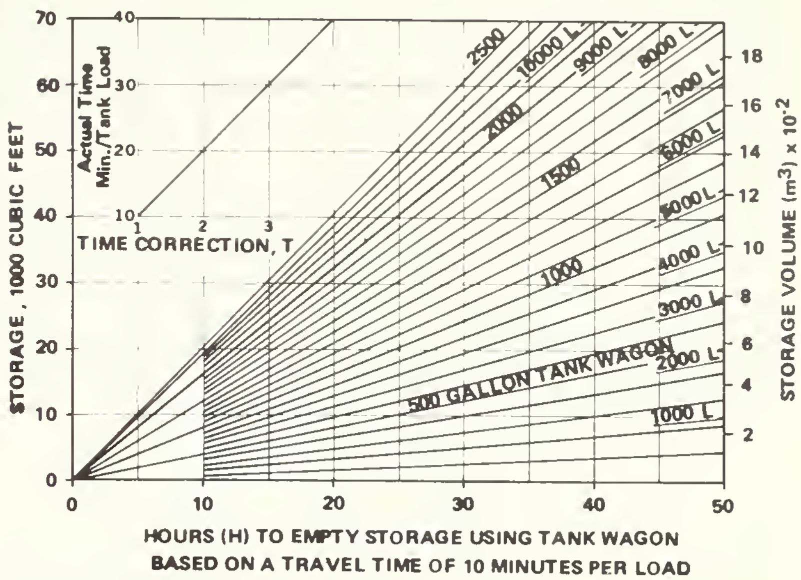


Figure 3.5.43 Time required to empty storage facility by various size tank wagons

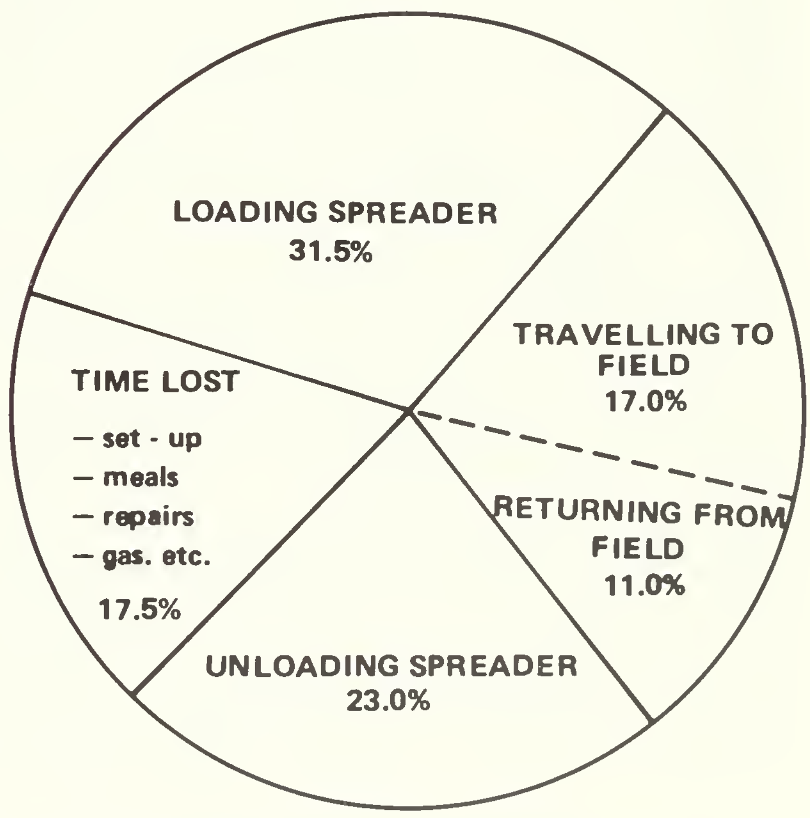


Figure 3.5.44 Overall proportions of time required for each land spreading process

3.5.7.5 Pumps

If manure is less than 10-12% solids the most economical method of handling will be likely by some type of mechanical pump, either for transfer from storage to transport vehicle or through pipeline and sprinkler irrigation systems.

Various sizes of solids can be handled by different manure pumps, usually from 25 to 75 mm. However, if the slurry is spread through a manure gun or special sprinkler nozzle, then the nozzle size must be large enough to pass any solids allowed to enter the system. Centrifugal irrigation pumps may handle 19 mm solids while trash pumps may handle 75 mm diameter solids. Auxiliary chopper blades are desirable when straw or hay may be present in the slurry.

Pressures at big-gun sprinklers are in the order of 415-895 kPa (60-130 psi). The pump must operate against (a) pressure head loss at the sprinkler, (b) velocity head loss at discharge, (c) friction head losses in the pipe line, and (d) suction head loss. If hydraulic agitation is to be used to stir the contents of the manure storage then velocity and pressure characteristics of the pump discharge are very important.

The flow properties of dairy manure slurries influence pumping power requirements. Staley et al. (27) and Hashimoto and Chen (13) have shown that these slurries behave as non-Newtonian fluids. Pressure drops for different pumping flow rates, solids content and nominal 3 and 4 in. aluminum irrigation pipe can be estimated from Figures 3.5.45 and 3.5.46. Additional information on pumps and flow of liquids can be found in Section 2.5, *Liquid Conveyors*.

The performance characteristics of a number of pumps were evaluated by Carson (7) when pumping dairy cattle manure with solids content ranging from 0.6 to 7.5%. Figures 3.5.47 to 3.5.66 are a selection of performance curves taken from this report. In general he found that most manufacturers were conservative in their published data. In most cases, however, the efficiency of pumps tested was reduced substantially at higher solids content of the slurry handled. The reduction occurred because power requirements remained nearly constant while the volume flow rate dropped with increased solids content.

Matching a manure pump to a particular application can be achieved by using Table 3.5.8 based on Carson's (7) report. By obtaining the pumping rate for a particular pump and percent solids, Figure 3.5.67 can be used to determine the pumping time for a desired application of manure slurry.

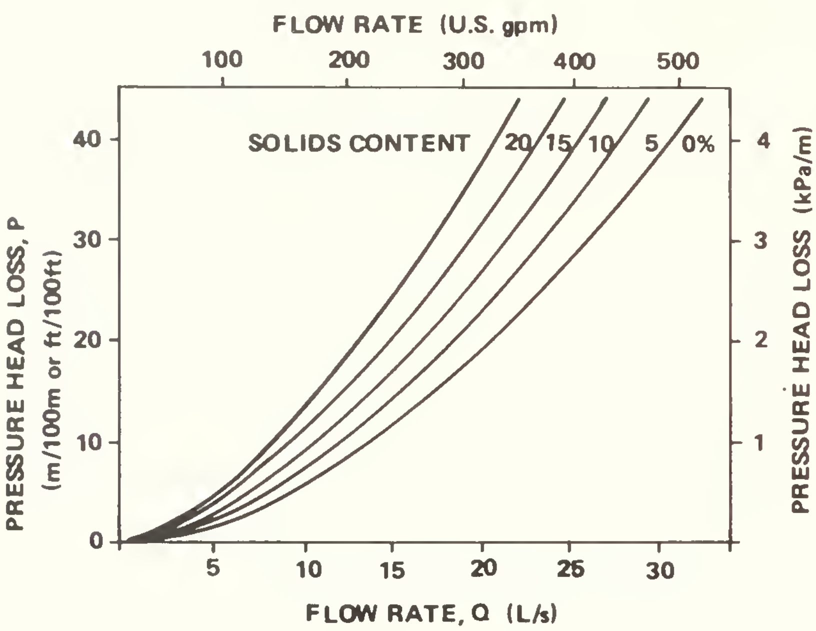


Figure 3.5.45 Pressure loss for dairy slurry in 3 in. aluminum irrigation pipe

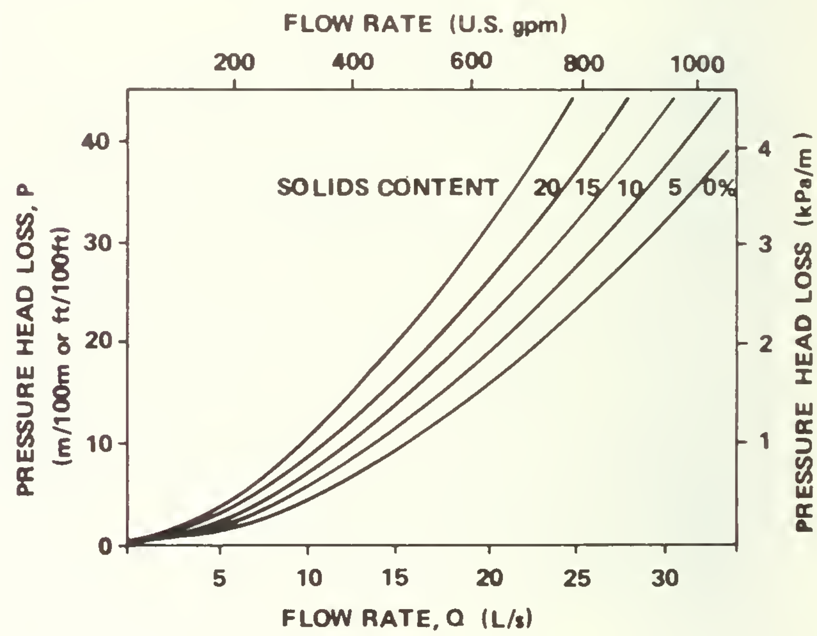


Figure 3.5.46 Pressure loss for dairy slurry in 4 in. aluminum irrigation pipe

TABLE 3.5.8 Guide for Pump Selection

Pump	Ease of Operation	Portability	Cost, $	Agitation	Recommended Discharge Range L/s	(ft³/s)	Recommended Head Range kPa	(ft)	Solids Content[1]
Bauer	good	good	2100	none	15.5-18.4	(0.55-0.65)	300-1200	(100-400)	L
					14.2-15.5	(0.50-0.55)	300-1200	(100-400)	M
					9.9-12.7	(0.35-0.45)	300-1200	(100-400)	H
Holz	good	good	2000	none	7.1- 9.9	(0.25-0.35)	150-750	(50-250)	L
					8.5-14.2	(0.30-0.50)	150-750	(50-250)	M
					8.5-12.7	(0.30-0.45)	150-750	(50-250)	H
Wright-Rain	fair	good	1200	none	17.0-18.4	(0.60-0.65)	150-570	(50-190)	L
					11.3-14.2	(0.40-0.50)	150-450	(50-150)	M
					8.5-11.3	(0.30-0.40)	150-525	(50-175)	H
Mitchell	good	fair	2740	fair	17.0-28.3	(0.60-1.0)	210-540	(70-180)	L
					11.3-22.7	(0.40-0.8)	270-570	(90-190)	M
Agpro	good	poor	4380	good	26.9-28.3	(0.95-1.0)	150-495	(50-165)	L
					12.7-14.2	(0.45-0.50)	225-525	(75-175)	M
					5.7- 8.5	(0.20-0.30)	240-450	(80-150)	H

[1]L-low (0.5%); M-medium (4%); H-high (7%)
From: Reference (7)

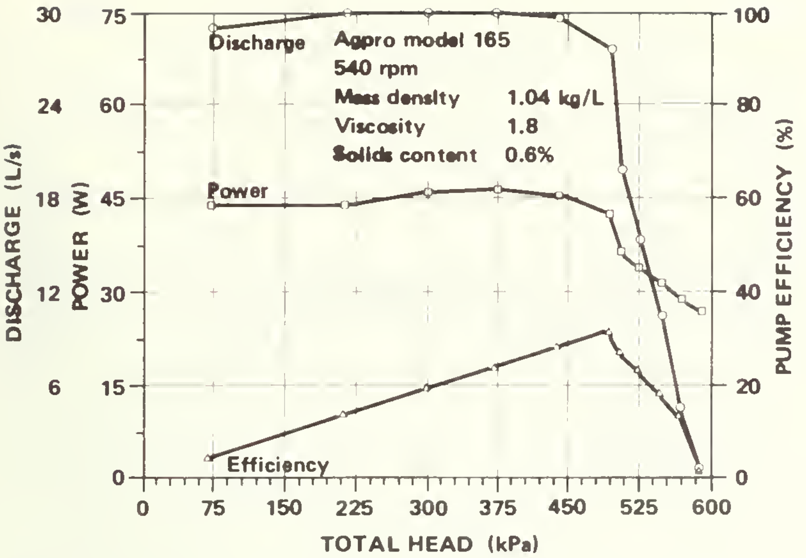


Figure 3.5.47 Agro pump model 165 and 0.6% solids

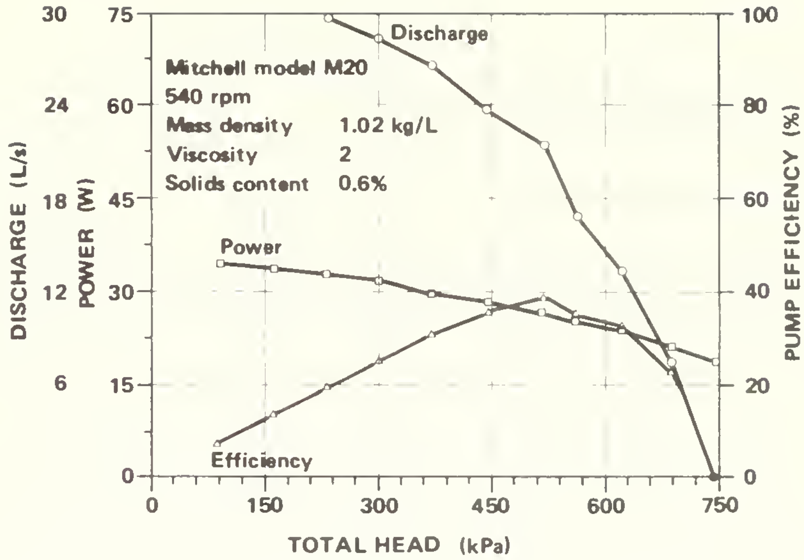


Figure 3.5.50 Mitchell pump model M20 and 0.6% solids

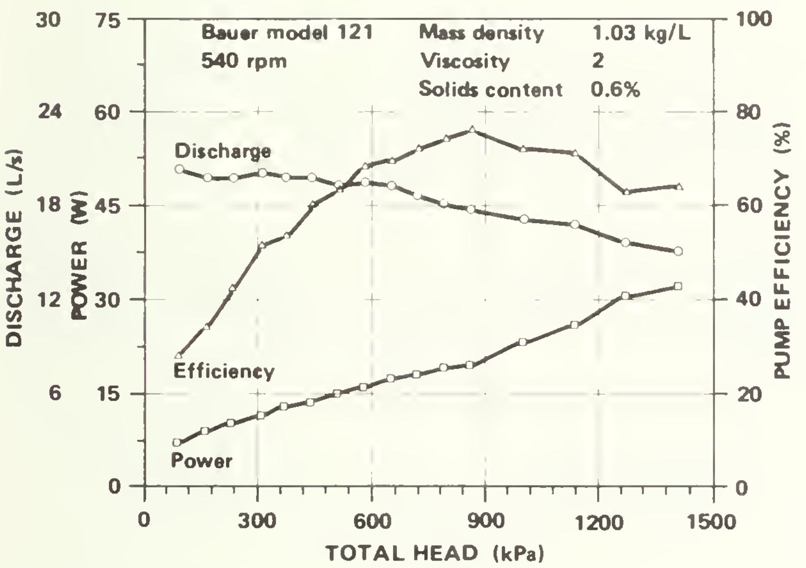


Figure 3.5.48 Bauer pump model 121 and 0.6% solids

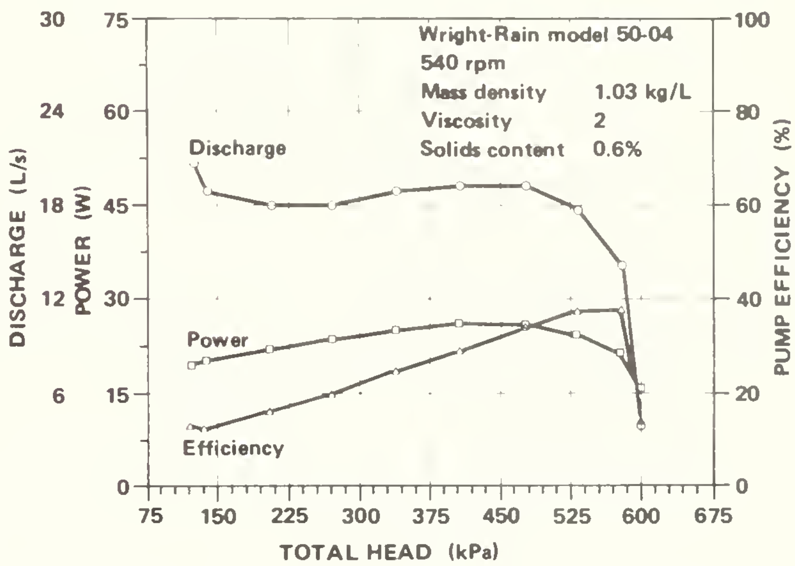


Figure 3.5.51 Wright-Rain pump model 50-04 and 0.6% solids

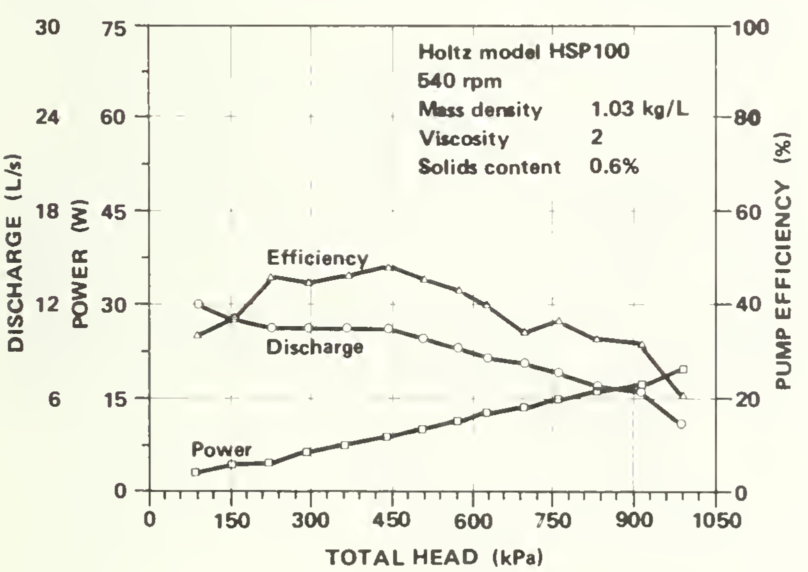


Figure 3.5.49 Holtz pump model HSP100 and 0.6% solids

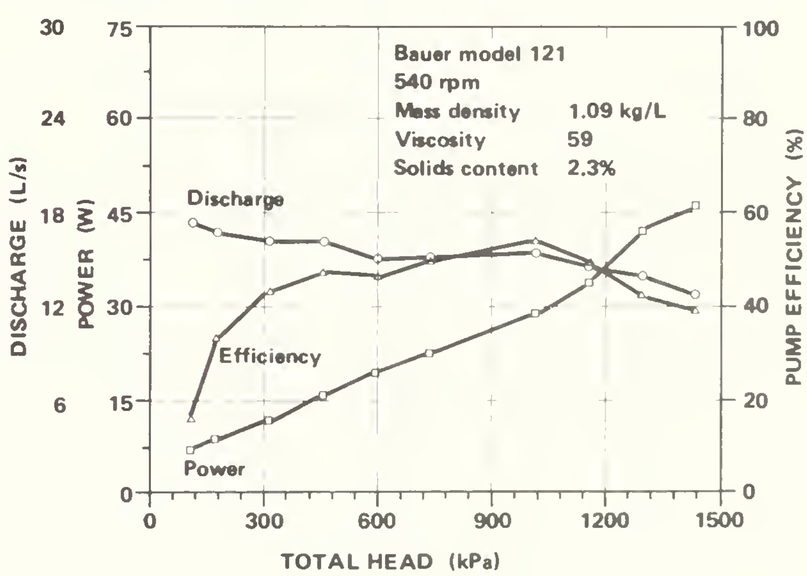


Figure 3.5.52 Bauer pump model 121 and 2.3% solids

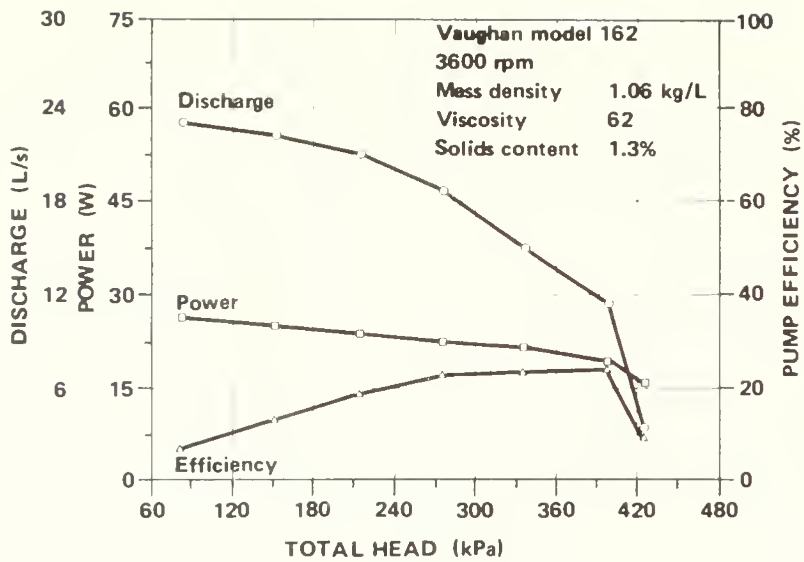


Figure 3.5.53 Vaughan pump model 162 and 1.3% solids

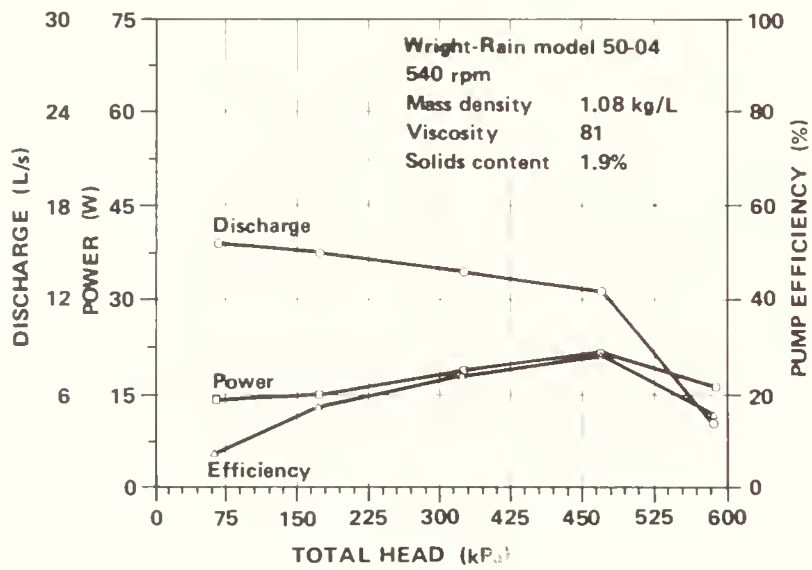


Figure 3.5.54 Wright-Rain pump model 50-04 and 1.9% solids

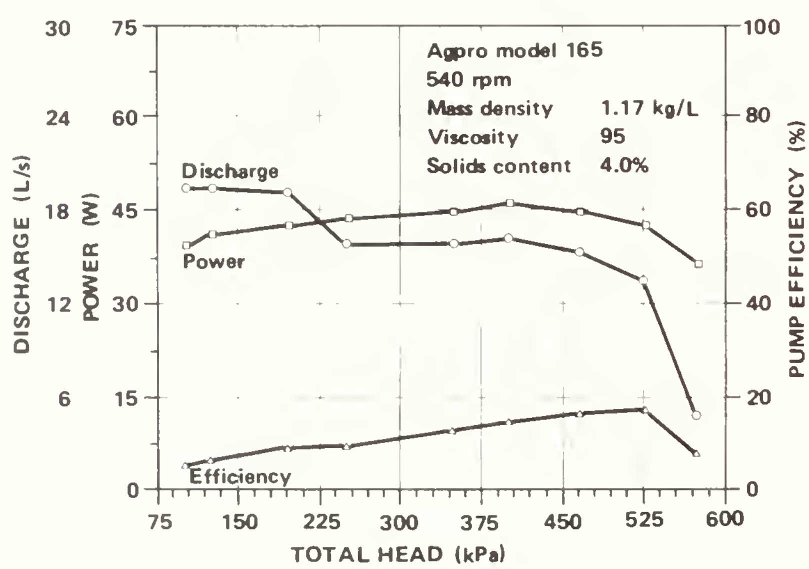


Figure 3.5.55 Agpro pump model 165 and 4% solids

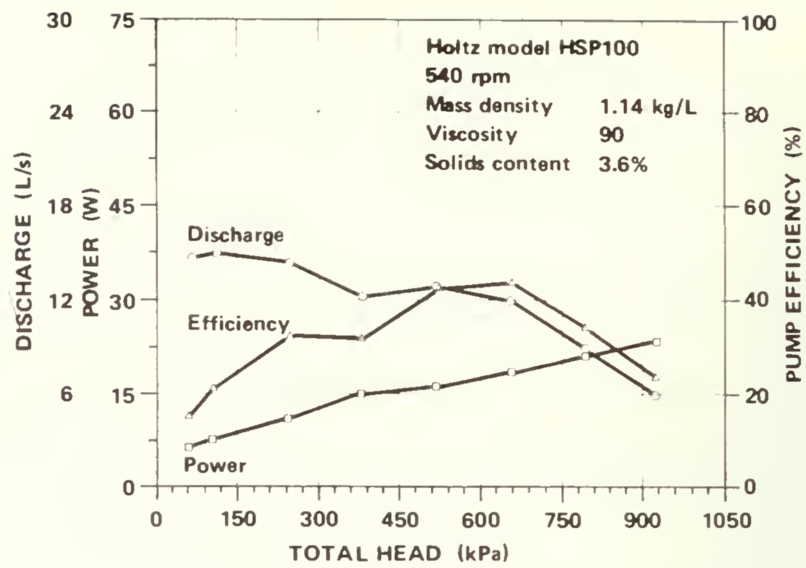


Figure 3.5.56 Holtz pump model HSP100 and 3.6% solids

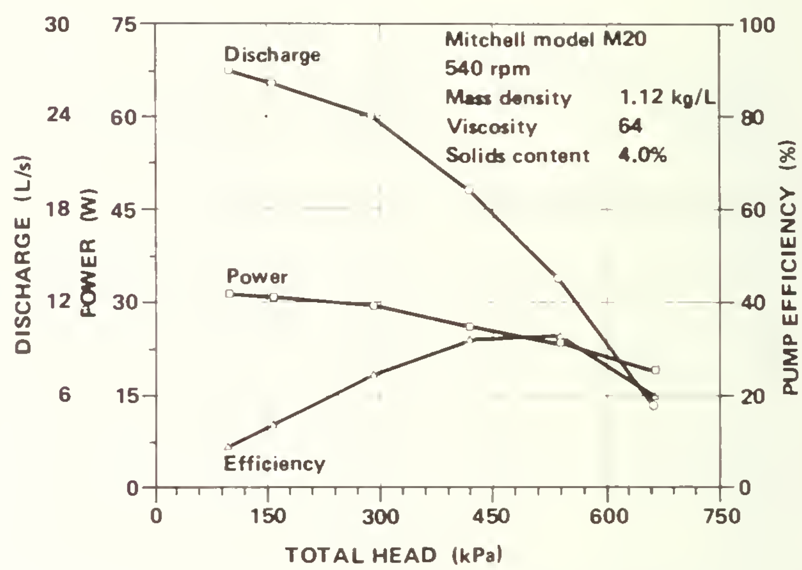


Figure 3.5.57 Mitchell pump model M20 and 4% solids

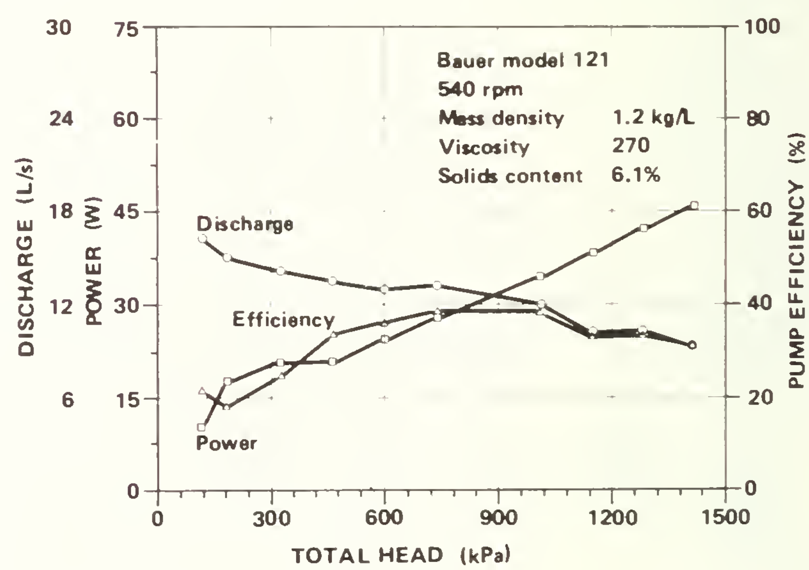


Figure 3.5.58 Bauer pump model 121 and 6.1% solids

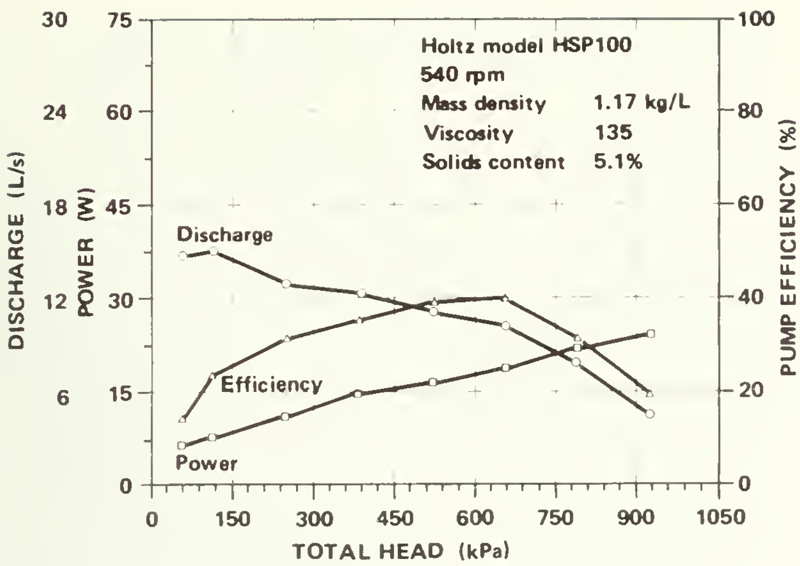


Figure 3.5.59 Holtz pump model HSP100 and 5.1% solids

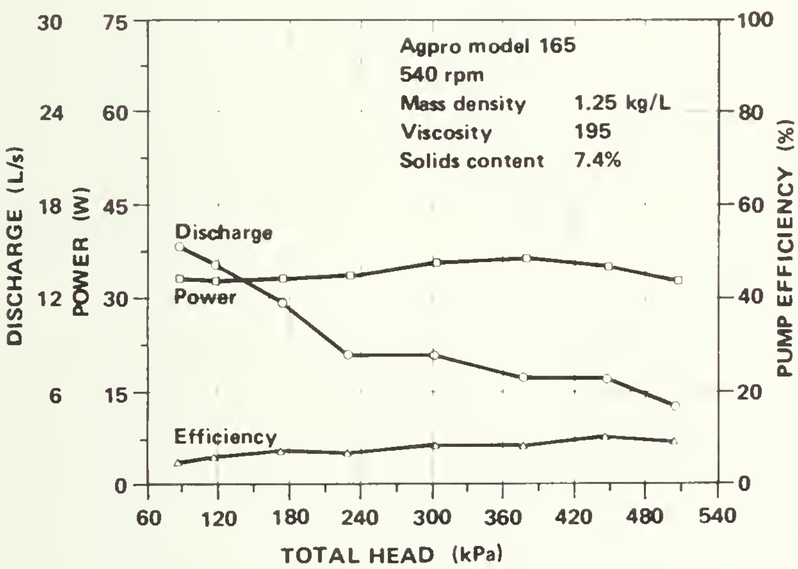


Figure 3.5.60 Agpro pump model 165 and 7.4% solids

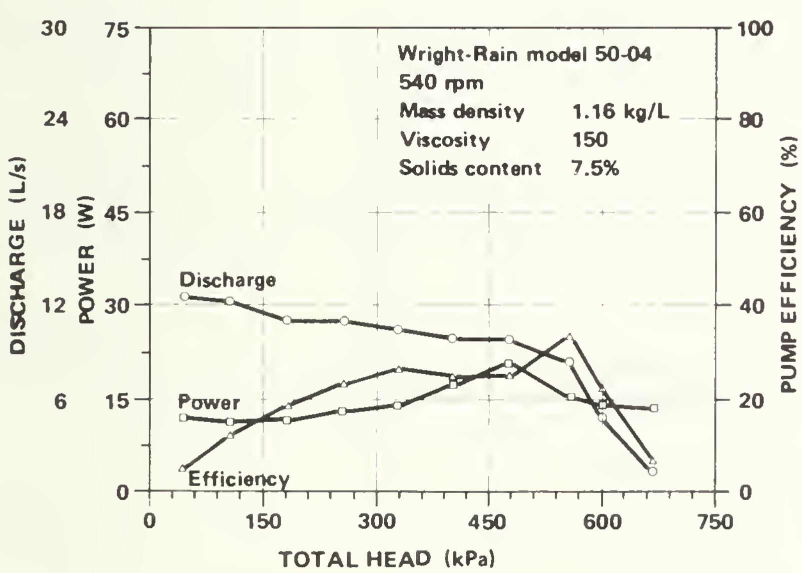


Figure 3.5.61 Wright-Rain pump model 50-04 and 7.5% solids

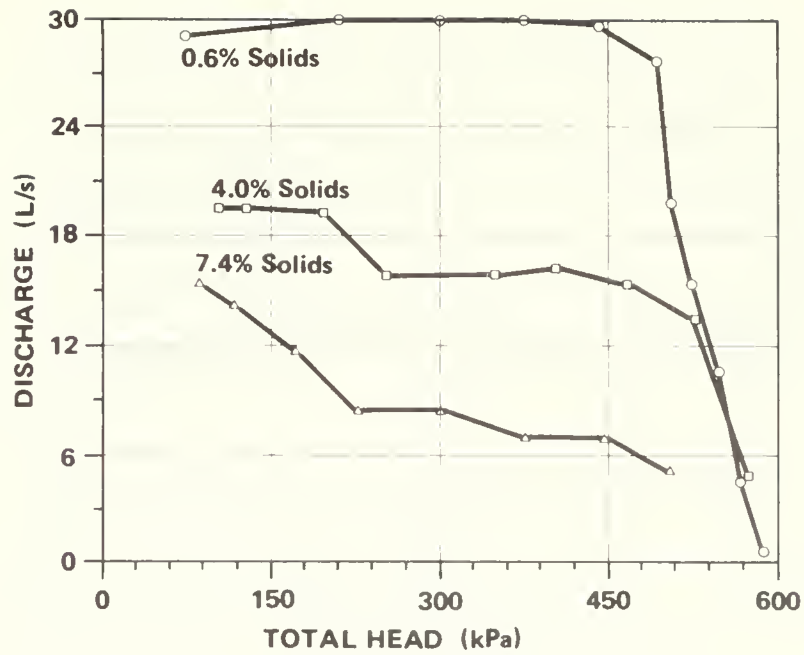


Figure 3.5.62 Agpro pump model 175 and 0.6, 4.0 and 7.4% solids

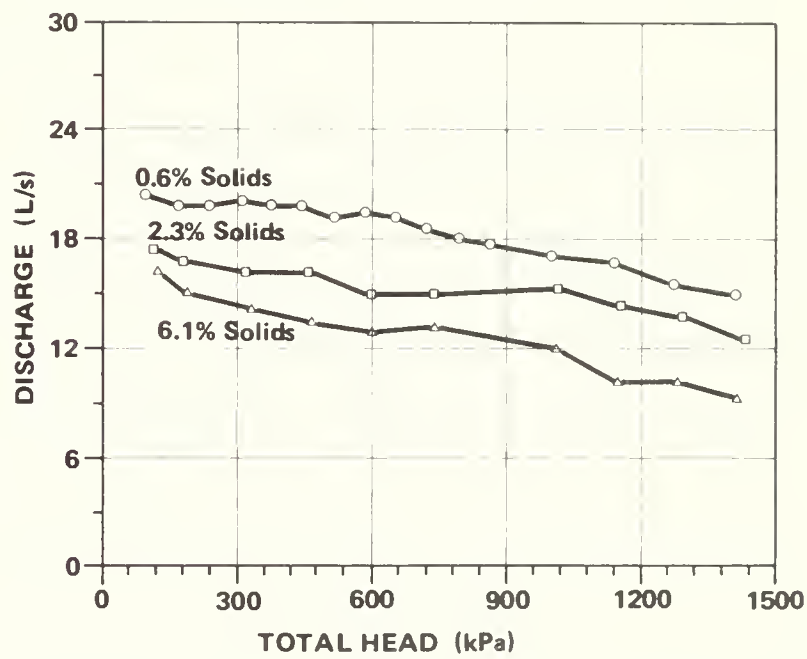


Figure 3.5.63 Bauer pump model 121 and 0.6, 2.3 and 6.1% solids

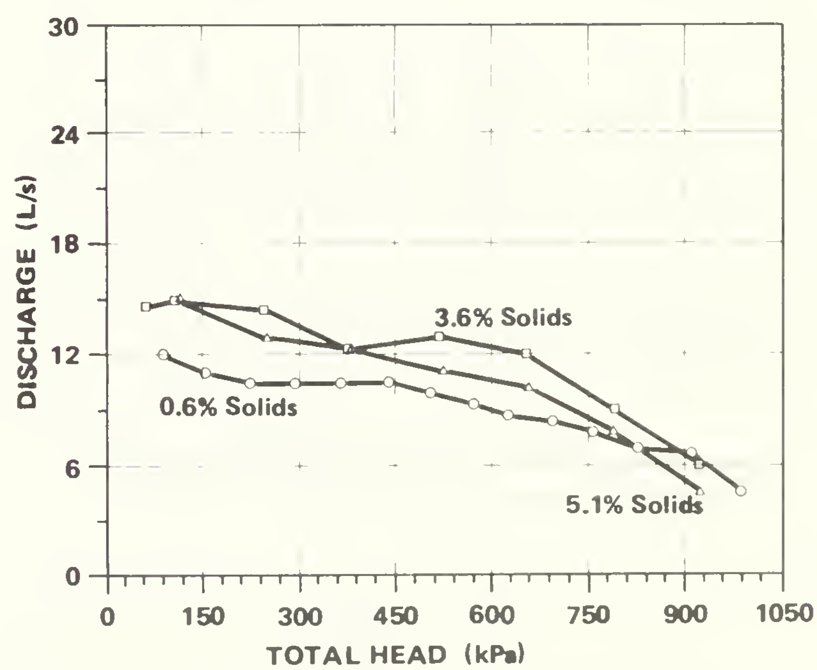


Figure 3.5.64 Holtz pump model HSP100 and 0.6, 3.6 and 5.1% solids

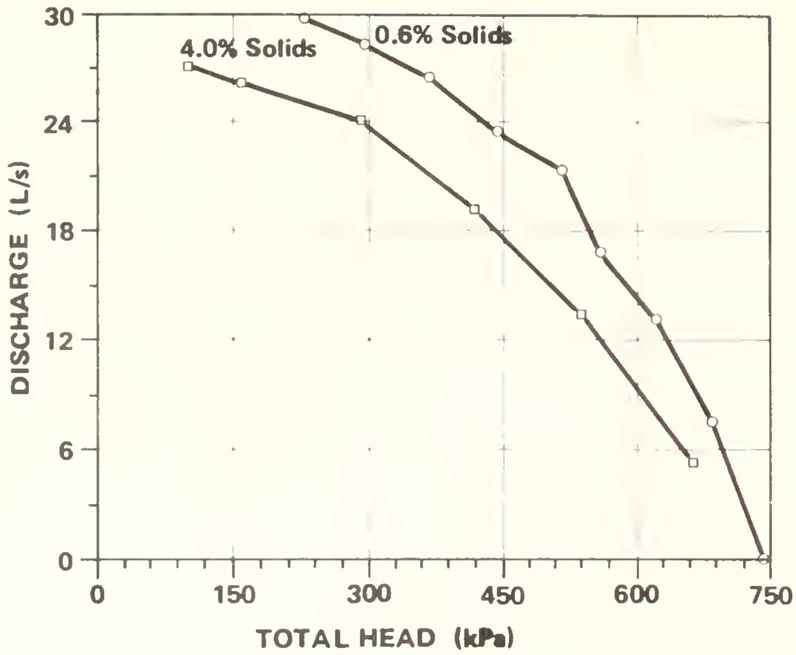


Figure 3.5.65 Mitchel pump model M20 and 0.6 and 4% solids

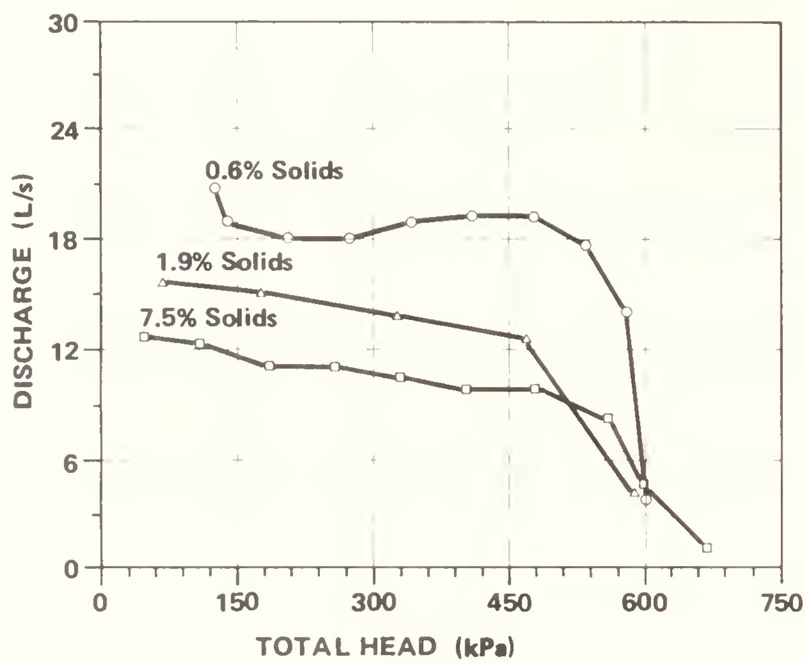


Figure 3.5.66 Wright-Rain pump model 50-04 and 0.6, 1.9 and 7.5% solids

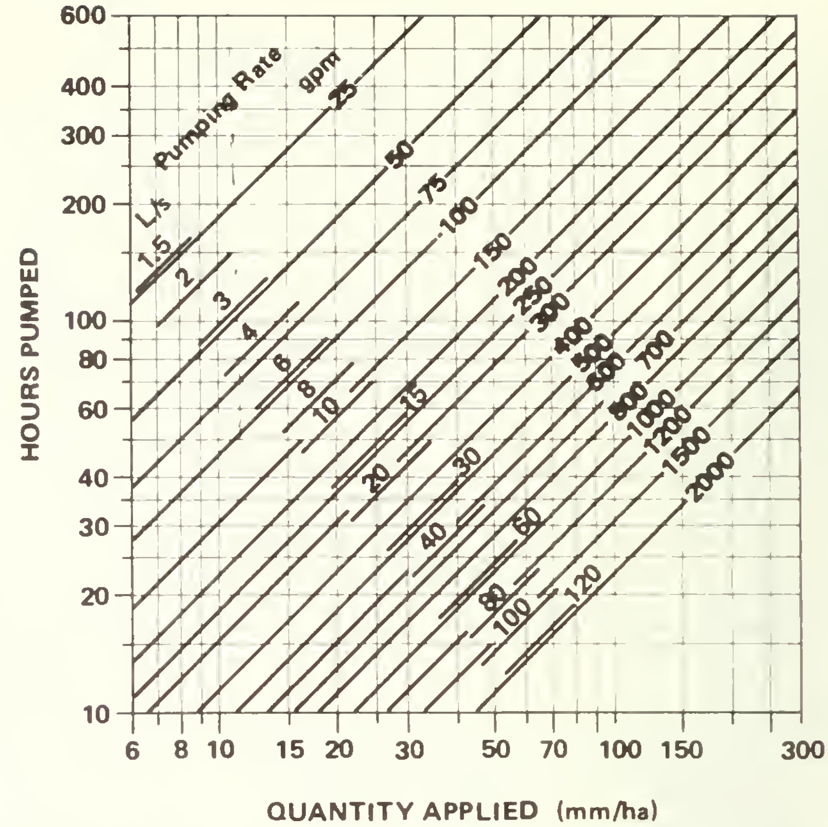


Figure 3.5.67 Pumping time required to deliver given mm depth on one hectare at various pumping rates

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